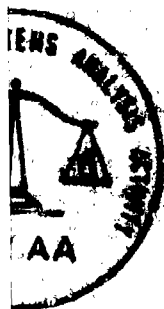


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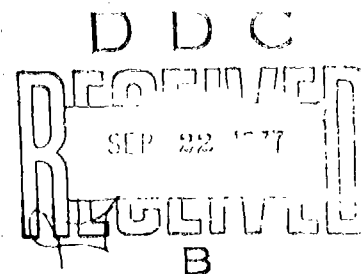
# AMSAA

TECHNICAL REPORT NO. 199

ANALYSIS OF THE VISUAL OBSCURATION PRODUCED BY  
CURRENT ARTILLERY AND MORTAR DELIVERED WP AND  
HC SMOKE

DOUGLAS N. WARRINGTON  
WILLIAM T. HIRNYCK

AUGUST 1977



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ANALYSIS OF THE VISUAL OBSCURATION PRODUCED BY CURRENT  
ARTILLERY AND MORTAR DELIVERED WP AND HC SMOKE

1. INTRODUCTION

1.1 Background.

A test was conducted at Fort Sill, Oklahoma from 8-15 December, 1975 in which single and multiple rounds of white phosphorus (WP) and hexachloroethane (HC) were fired from the 105mm and 155mm howitzers, and WP from the 60mm, 81mm and 4.2 inch mortars. The proponent of the test was the US Army Materiel Systems Analysis Activity which was supported by the U S Army Field Artillery Board and the U S Army Field Artillery School.

The objectives of the test were to:

- a. provide baseline data for artillery and mortar smoke munitions using current techniques and procedures as outlined in the training literature (TC 6-20-5),
- b. obtain data for use in validating the JTCG/ME Smoke Obscuration Model,
- c. provide data for an evaluation of the attenuation of current artillery and mortar delivered WP and HC smoke at the 0.4-0.7, 0.7-1.1, 3-5, and 8-14 micrometer ( $\mu$ ) regions of the spectrum,
- d. provide data for an evaluation of the effect of WP and HC smoke on the TOW and DRAGON missile systems,
- e. provide data for an evaluation of the effectiveness of the AN/TAS-3, 4, and 5 night vision devices, of crew served weapons systems and of the M37 gunner sight in a WP and HC smoke environment during day and night firings,
- f. provide data for an evaluation of the time history of visibility between target and observer.

This report addresses objective f from the list above. Test objectives c, d and e were addressed in AMSAA Technical Report 183. The Field Artillery School is using the information from the test to update this personnel training and smoke utilization techniques (objective a). Another division within AMSAA is utilizing the data to validate the JTCG/ME Smoke Obscuration Model (objective b). The material in this background section is presented in order to familiarize the reader with the objectives, concept and conduct of the Ft. Sill Smoke Test.

Operationally, the effectiveness of the cloud and screen were assessed relative to obscuring stationary targets from observers who were positioned on the western periphery of the target area. Smoke screens were formed by single and multiple rounds of WP and HC munitions. The firings were conducted by one battery of 155mm howitzers, one battery of 105mm howitzers, one platoon of 4.2 inch mortars, one platoon of 81mm mortars, and one platoon of 60mm mortars. The batteries and platoons were registered prior to each day's firings. Each caliber was fired separately with missions being fired in the morning and afternoon. Night firings were conducted with the 155mm HC, 105mm HC and the 4.2 inch WP to measure the effect of smoke on the night vision devices and for possible tactical employment. At least one mission for each 4.2 inch WP, 105mm HC and 155mm HC was fired to maintain a smoke screen for approximately 10 minutes.

The effectiveness and characteristics (size, geometry, formation) of the screens were documented visually and by instrumentation through use of cameras, video recorders, photometric-radiometric equipment and night vision equipment.

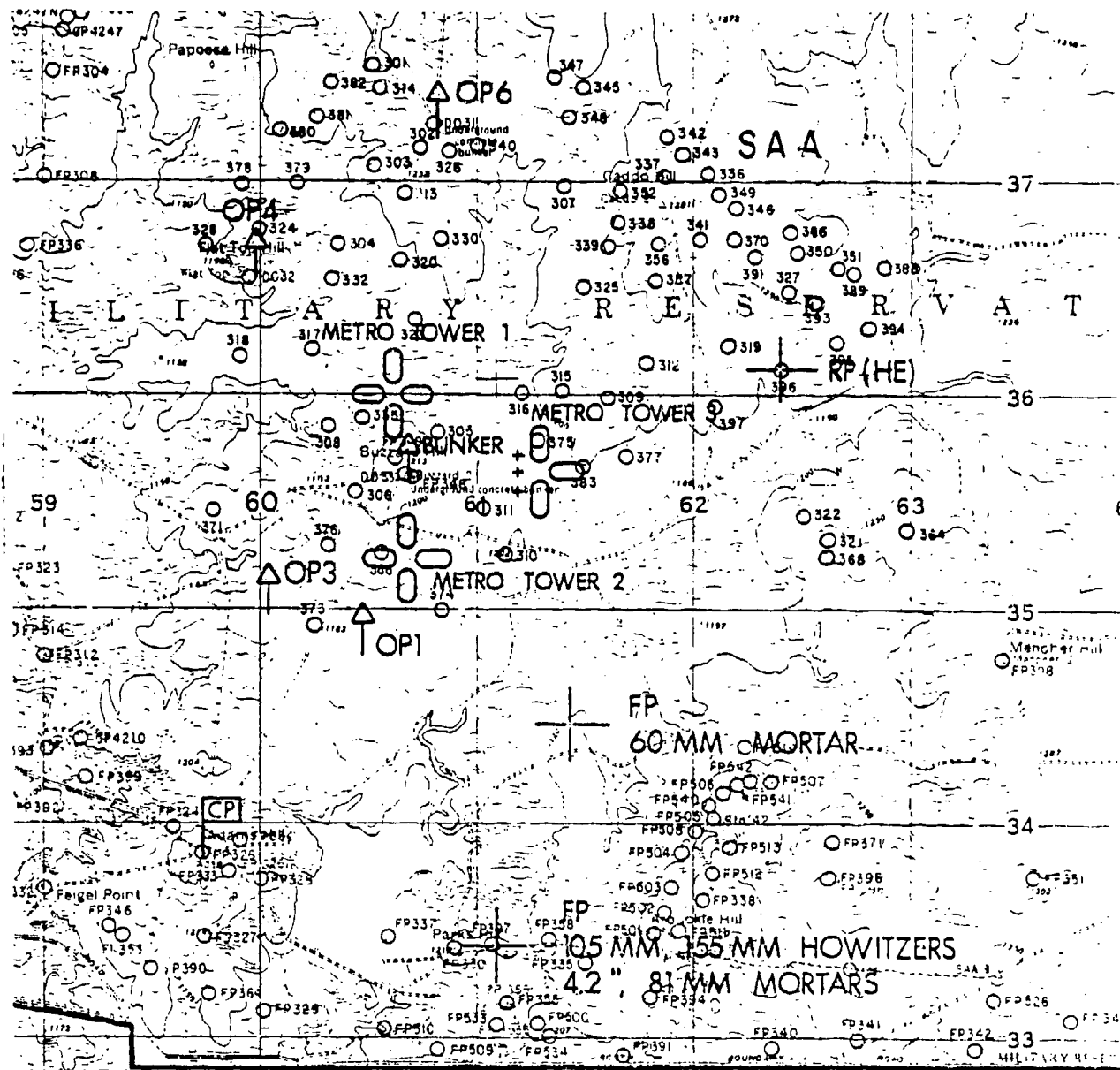
The test was fired by artillery and infantry units attached to the U S Army Field Artillery School. In a controlled test environment, rounds which are statically detonated to control placement of the smoke cloud and cloud dimensions could produce different results. The battery/platoon exercised practices and procedures which are necessary for the delivery of timely and accurate fire. Thus, this test produced results which more realistically represent an actual field operation.

The test site is shown in Figure 1.1. The site consisted of the following: the command post, two firing positions, three meteorological towers, which recorded wind speed, wind direction and temperature at 1/2 meter, 4 meter and 16 meter heights, three stationary targets, four observation posts and a bunker which, in addition to providing a base from which to operate instrumentation for other phases of the test, also operated as an observation post.

The instrumentation, personnel and equipment at each location consisted of:

- (1) FEBA: (Includes grid area forward of FEBA)
  - 5 - 8 feet by 8 feet panels
  - 2 - 5 kilowatt/60 Hertz generator
  - 2 - Beacon (DRAGON/TOW)
  - 1 - Light Source (for Ballistic Research Laboratories, BRL)

Figure 1.1 Layout of Test Range at Ft. Sill Showing the Location of the Targets, Bunker and OP's, Command Post, Meteorological Towers, Registration Point and Firing Positions.





- 1 - IR Source (for BRL)
- 1 - Contrast Disc (for BRL)
- 2 - CONEX (for BRL)
- 2 - M60 Tanks (1 with IR source and 1 backup)
- 1 - Black Box with 4-feet by 4-feet opening
- 1 - 36-volt direct current source

(2) BUNKER:

(a) Inside:

- 1 - 35mm camera (50mm lens)
- 1 - DRAGON system
- 2 - DRAGON Night Sight (AN/TAS-3 and AN/TAS-5)
- 2 - Transmissionometers (BRL)
- 4 - TA 312 Telephone with headset
- 1 - Pyroelectric vidicon

(b) Outside:

- 1 - CONEX
- 1 - 10 kilowatt/60 Hertz generator

(3) ATMOSPHERIC SCIENCES LABORATORY (ASL) TOWERS - 3 each

- 1 - 5 kilowatt/60 Hertz generator
- 1 - 25-Meteorological Van (at South Tower only).
- 1 - 10 kilowatt/60 Hertz generator (at Meteorological Van). All meteorological equipment were installed on towers by ASL.

(4) OBSERVATION POSTS:

(a) All Observation Posts.

- 1 - 35mm Camera with appropriate lens
- 1 - Tripod

- 1 - TA 312 with headset
- 1 - 1/4 Ton (or 5/4 ton) with AN/VRC-46 with driver.
- 1 - Observer/recorder
- 3 - Stadia markers

(b) Observation Post 1 (same as (a)) plus Crew Served Weapon System.

(c) Observation Post 3 (same as (a)) plus

- 1 - Sony Video Recorder
- 1 - Visual Contrast Measure
- 1 - Visibility measurer
- 1 - 1.5 kilowatt/60 Hertz generator
- 1 - TA 312 with headset (additional)
- 1 - CONEX
- 1 - M60A1 Tank/M32 and M36 sights
- 1 - TOW system
- 2 - Night Sight (TOW) AN/TAS-4
- 1 - M32 Gunner's sight

(d) Observation Post 4 (same as (a)) plus

- 1 - Sony Video Recorder
- 1 - 1.5 kilowatt/60 Hertz generator
- 1 - TA 312 with headset

(5) HELICOPTER UH-1:

- 1 - 16mm camera

(6) Three stadia rods, marked at 1/2 meter intervals, were placed at observation posts 1, 3 and 6. The purpose of these stadia rods was to reference cloud height for photographic interpolation.

(7) Observers positioned at each of the observation posts recorded time history of visibility between target and observer.

#### 1.2 Analysis Objectives.

The purpose of this report is to analyze the time history of visibility between the targets and the observers. All observations by the observers were made with the unaided eye. The obscurations resulting from each type of smoke round were evaluated to determine the effects of observer lines of sight and the number of rounds fired. The variability due to the type of smoke round fired is also investigated.

AMSAA Technical Report, Number 183 addressed the following items: the attenuation through smoke of the 0.4-0.7, 0.7-1.1, 3-5, and 8-14 micrometer regions of the electromagnetic spectrum, the effect of smoke on the DRAGON and TOW weapon systems, and the effect of smoke on the AN/TAS-3, 4 and 5 night vision devices.

## 2. SUMMARY

### 2.1 Analysis Summary.

The data from each of the observer positions were first grouped as to the type of smoke round fired and then the number of rounds fired. It was found that the largest sample of missions was obtained by selecting the 2, 4, and 6 round firings of the 155mm and 105mm (WP and HC) artillery and the 4.2 inch WP mortar, and the 1, 3, and 6 round firings of the 81mm and 60mm (WP) mortars. These missions were then used in the analysis.

The average time from impact to obscuration and the average time of obscuration for each type of smoke round and number of rounds fired were calculated and plotted for each of the observer positions. The data obtained from OP1, OP3, OP6, and the Bunker were used in this analysis since they were more complete. Data from OP4 were incomplete and, therefore, were not used in the analysis. Time history plots of these data were generated for each OP as a function of the number and type of rounds fired. The plots were then examined to determine if they followed the logical sequence that might be expected, taking into consideration the prevailing meteorological conditions, the average round impact area, and the typical behavior of the type of rounds being fired. An overlay showing the targets, OP's, round impact area, and meteorological conditions was made for each type of smoke round to aid in this analysis and is included in this report. Also shown on this overlay is the screening efficiency of the platoon/battery size firings as determined at each of the observer positions. The screening efficiency gives some measure of the availability of the target when smoke is present. The screening efficiency (SE) is defined as,

$$SE = \frac{\text{time target obscured}}{\text{total time}}$$

where the total time is from impact, through obscuration, and until time of target detection. These measures assisted to envisage the relationships among the observer positions for the missions analyzed.

An Analysis of Variance (ANOVA) was performed to determine if the number of rounds fired and the observer positions had any significant effect on the time of smoke obscuration. An ANOVA was performed for each type of smoke round fired in the test.

When a battery fires one volley (6 rounds), one may expect a significant increase in the time of obscuration over the time when only two rounds are fired. The ANOVA showed, however, that there was no significant difference at the 0.05 level of significance in the duration of obscuration due to an increase in the number of rounds fired. (Only missions of one to six rounds were considered). This then would seem to imply that obscuration of a point target would best be accomplished by firing one or two rounds followed at some time interval by one or two

additional rounds. The interval then would depend on the type of round being used, meteorological conditions, etc. When a larger cloud is desired to obscure several targets, it would be necessary to fire more rounds with the proper dispersion. Duration of obscuration would not significantly increase, but the length of the smoke cloud would increase. In that case, cloud length is the more desired result.

The ANOVA also showed that in this test the observer position had no significant effect on the duration of smoke obscuration at the 0.10 level of significance. Even though the observer positions varied greatly in distance to the targets (from 510 to 1750 meters) and also in the angle of incidence to the line of the smoke clouds, no statistically significant difference was found. The time to obscuration did vary more, however. These differences were more a result of the wind conditions and the placement of rounds in relation to the targets and observer positions. Differences in the time to obscuration should be expected because of the aforementioned factors. What was stressed by this analysis, however, was the fact that even though there were differences in the duration of the obscuration due to the positioning of the observers, they were not statistically significant at the levels tested.

The effect of these two factors (number of rounds and observer positions) was not significant at even higher levels of significance for some types of rounds than those previously stated. These levels of significance are shown in Table 2.1. This table is intended only to stress the fact that the number of rounds fired and the observer position did not significantly affect the duration of the smoke obscuration, and also to show a summary of the ANOVA results for each type of round. The table should not be used to compare capabilities between the rounds. Those comparisons should be made by using the average time to obscuration and average time of obscuration for each type of round as found in Section 3.

TABLE 2.1 Significance Levels (from F tables) where Factors No Longer Significantly Effect the Time of Obscuration.

Type Smoke	Factor	Significance Level of Factor	
		Observer Position	Number of Rounds
155mm WP		.10	.25
155mm HC		.25	.10
4.2 Inch WP		.25	.05
105mm HC		.25	.25
105mm WP		.10	.25
81mm WP		.25	.10
60mm WP		.10	.05

After examining each type of smoke round separately, the obscuration ability as observed from the bunker was analyzed. Figure 2.1 shows the time history of the average mission as observed from the bunker. The time histories are functions of the type of smoke round and the number of rounds fired. It appears from these graphs that there is a significant difference in the time of obscuration among the various types of smoke rounds. An Analysis of Variance showed that (again) the number of rounds did not significantly affect the obscuration time, even at the 0.25 level. However, the analysis showed that the type of round fired was highly significant. A Newman-Keuls range test was applied to examine the effects among the types of rounds (Reference 1). The test showed which type of round is significantly better than another type of round at the 0.05 level of significance. These comparisons are detailed in Section 3.9 and are summarized in the conclusions, Section 2.2.

Since the number of rounds fired in a single volley and the observer positions were not significant factors affecting the time of obscuration, the data were combined. An average time to obscuration and time of obscuration were calculated for each type of smoke round. The standard deviation was also calculated. This type of information should be useful to a forward observer in determining the type of rounds he needs to fulfill his mission requirements.

## 2.2 Conclusions.

Based on the analysis of the observer data from the Ft. Sill Smoke Test, the following conclusions are reached:

- In smoke missions of one to six simultaneously fired rounds, there were no significant differences in the duration of the obscuration due to the different observer positions or the number of rounds fired. Although duration did not significantly increase with the number of rounds fired, the width of the smoke cloud and thus the total area obscured does increase (due more to good round dispersion than number of rounds fired).
- The 155mm HC was significantly better as it pertains to smoke duration than all the other types of rounds ( $\alpha=0.05$ ). The 4.2 inch WP and the 155mm WP were significantly better than either the 81mm WP, the 105mm WP, or the 60mm WP smoke rounds. The 105mm HC was significantly better than either the 105mm WP or the 60mm WP. There were no significant differences in the visual obscuration capabilities of either the 155mm WP, the 4.2 inch WP or the 105mm HC smoke at the 0.05 level.

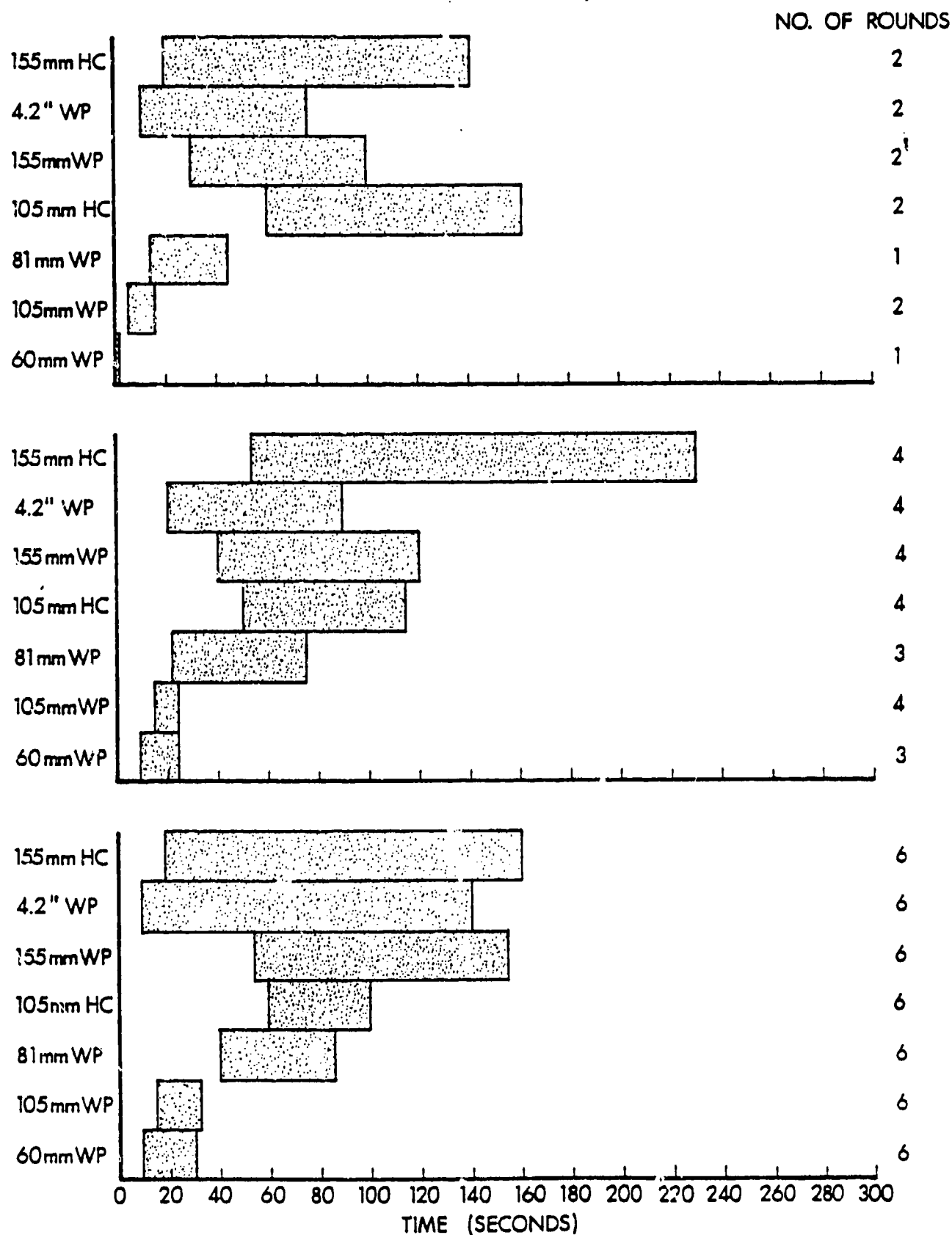


Figure 2.1 Time History of Obscuration of the Average Missions as Observed from the Bunker. Round(s) Impact is at Time 0 and the Obscuration is Shown by the Shaded Area.

### 3. DETAILS OF ANALYSIS

#### 3.1 Description of Data.

Army Field Artillery observers from the U. S. Army Field Artillery School were deployed at five observation posts located on the periphery of the impact area, as shown in Figure 3.1. One observer was stationed at each observation post (OP). Using the observer-target line between the bunker (B) and the center target as a reference line ( $0^\circ$ ), the line-of-sight angles and distances between the OP's and the center target are given below in Table 3.1.

TABLE 3.1 Observer to Target Angles and Distances

Observation Post	Angle to Target	Distance to Target (Meters)
1	$-47^\circ$	1040
3	$-28^\circ$	1350
Bunker	$0^\circ$	520
4	$38^\circ$	1550
6	$79^\circ$	1750

The observers were instructed to record the time of impact, the time when obscuration occurred, the time to target detection and the time to target recognition. For the purpose of this analysis, only the first three items were considered. Observer commentary was also encouraged.

From these data, the time from impact to target obscuration and the time the target was obscured were determined for each of the observer positions and for each type of smoke round. Data from OP4 was fractional and incomplete. Therefore, only OP1, OP3, OP6, and the bunker data were used in this analysis.

The analysis endeavors to show relationships among the observer positions, round impact area, and meteorological conditions. The average time to obscure the target and the average time of obscuration were calculated for each observer position, type of round, and number of rounds. The analysis assumes that the center target is under obscuration, unless stated otherwise. The instructions to the fire direction center were to place the rounds approximately 50 meters in front of the targets and upwind from the targets.



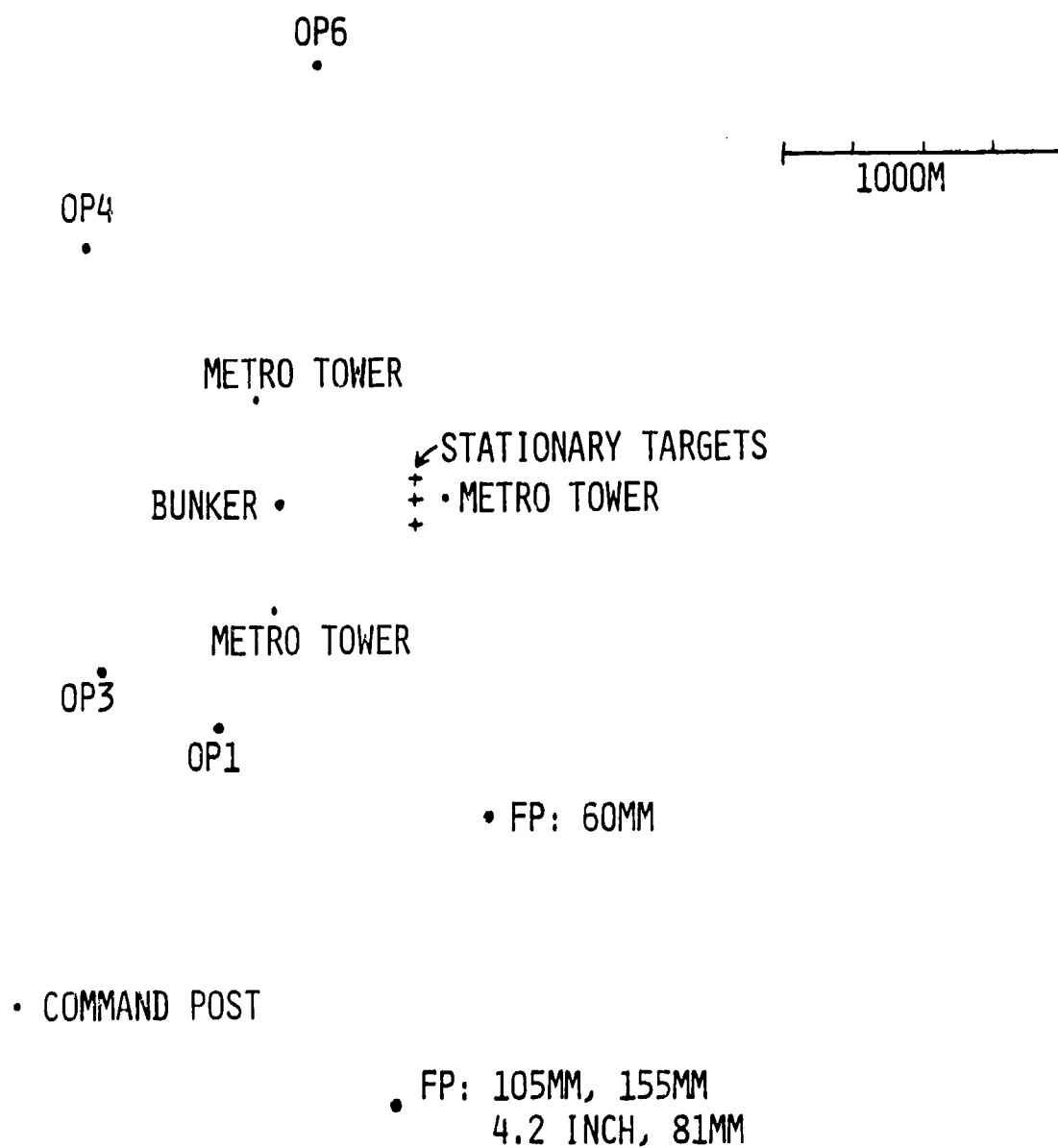


FIGURE 3.1 LOCATION OF OBSERVER POSITIONS (OP1, OP3, OP4, OP6, AND BUNKER) DURING THE FT, SILL SMOKE TEST.

### 3.2 155MM White Phosphorus.

As shown in Figure 3.2, the rounds impacted slightly south and in front of the south target. In general, a lapse condition existed during these missions. Here, and throughout the report, a lapse condition refers to a decrease in temperature with increasing altitude. Wind velocities shown are those reported by the meteorological stations. With the wind blowing generally from the south at about 8 miles per hour, the smoke should drift over the other targets as time progresses. Since WP is a quick smoke, the smoke should build up rapidly in the area of the south target, obscuring the targets from the observer at OP1 first, OP3 second, bunker third, and OP6 last. Logically, this is how the smoke should behave.

Figures 3.3a and 3.3b show the average time to obscuration and the average obscuration time at the four OP's for 2, 4, and 6 rounds. These figures show that the time to obscuration does increase going clockwise around the targets from OP1 to OP6. An Analysis of Variance (ANOVA) was performed on the time of obscuration data to determine whether the observer position or the number of rounds fired had a statistically significant effect on the time of obscuration. This analysis showed that the effect of the observer position on the time of obscuration was not statistically significant at the 0.10 level of significance. The number of rounds fired was not statistically significant at the 0.25 level. For an explanation of Analysis of Variance, statistical inference, tests of hypotheses and level of significance, see reference 1. (Any subsequent reference to significance in this report refers to statistical significance).

Although neither factor had a significant effect on the time of obscuration at the levels tested, this does show that the observer position had more effect on obscuration time than did the number of rounds fired, since the observer position factor could not pass the test at the 0.25 level. Observer positions varied in distance to the target and angle of incidence to the smoke, so a greater effect is expected. What may be unexpected, however, is the fact that obscuration time did not significantly increase with the number of rounds fired. The most probable explanation for this is that the higher concentration of smoke produced by the larger number of rounds fired is redundant to a visually unaided forward observer. The smoke rounds will all diffuse at approximately the same rate, so a doubling or tripling of the obscuration time is not expected with the proportionate increase in the number of rounds fired simultaneously. Increases in obscuration time can be expected for multiple rounds which are appropriately placed upwind of the targets. However, when attenuation of weapon system IR track links and thermal night sights is desired, the greater concentrations of smoke are required. (See AMSAA Technical Report TR-183).

OP	TIME TO/OF OBSCURATION	SCREENING EFFICIENCY
1	4.8/78.6 SEC	0.94
3	25.5/76.6 SEC	0.77
8	54/102 SEC	0.65
6	84/228 SEC	0.73

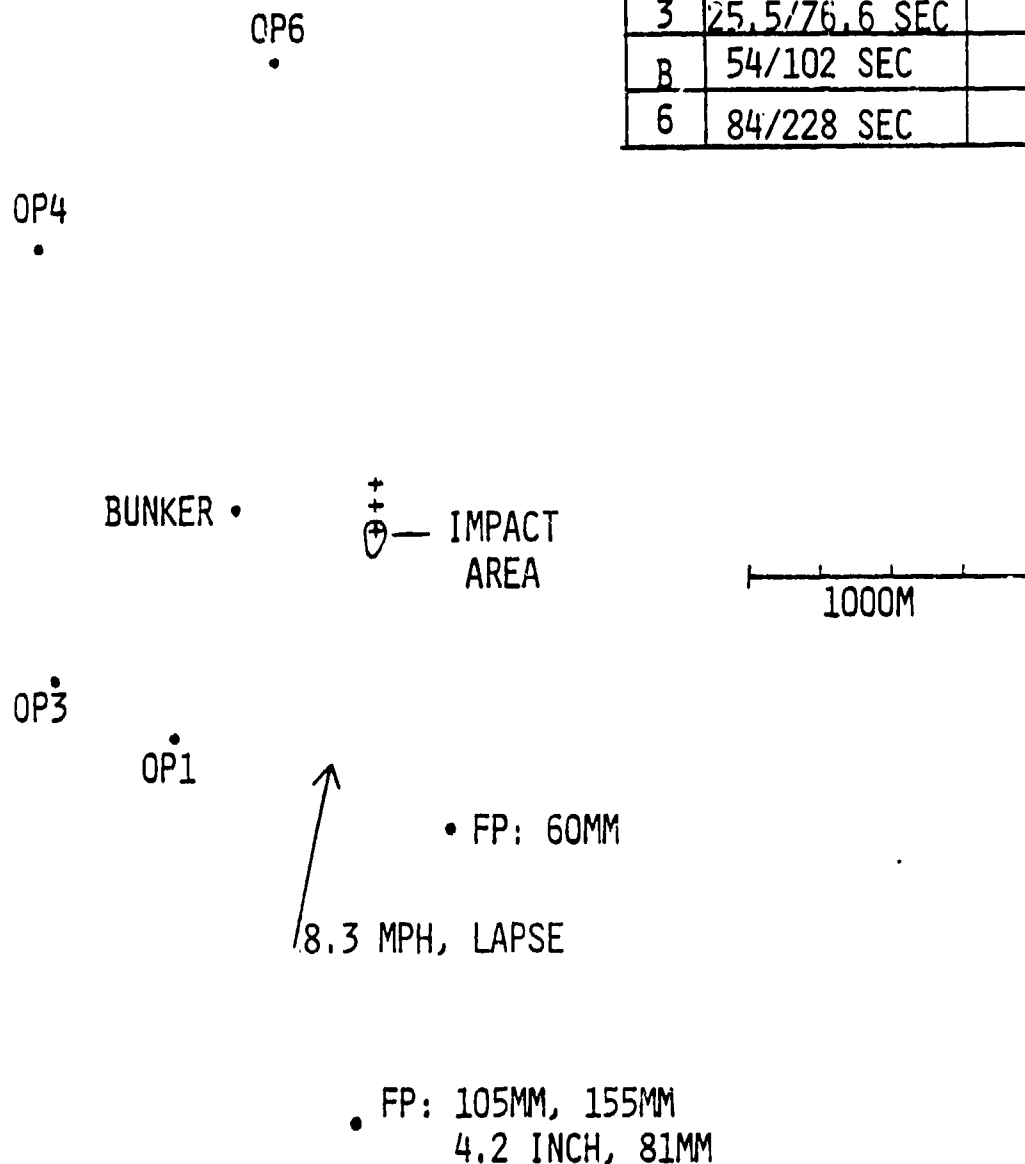


FIGURE 3.2. WIND CONDITIONS AND ROUND IMPACT AREA OF THE 155MM WP SMOKE IN RELATION TO THE OBSERVER POSITIONS. SCREENING EFFICIENCY AT EACH POSITION IS ALSO LISTED FOR THE 6 ROUND MISSIONS.

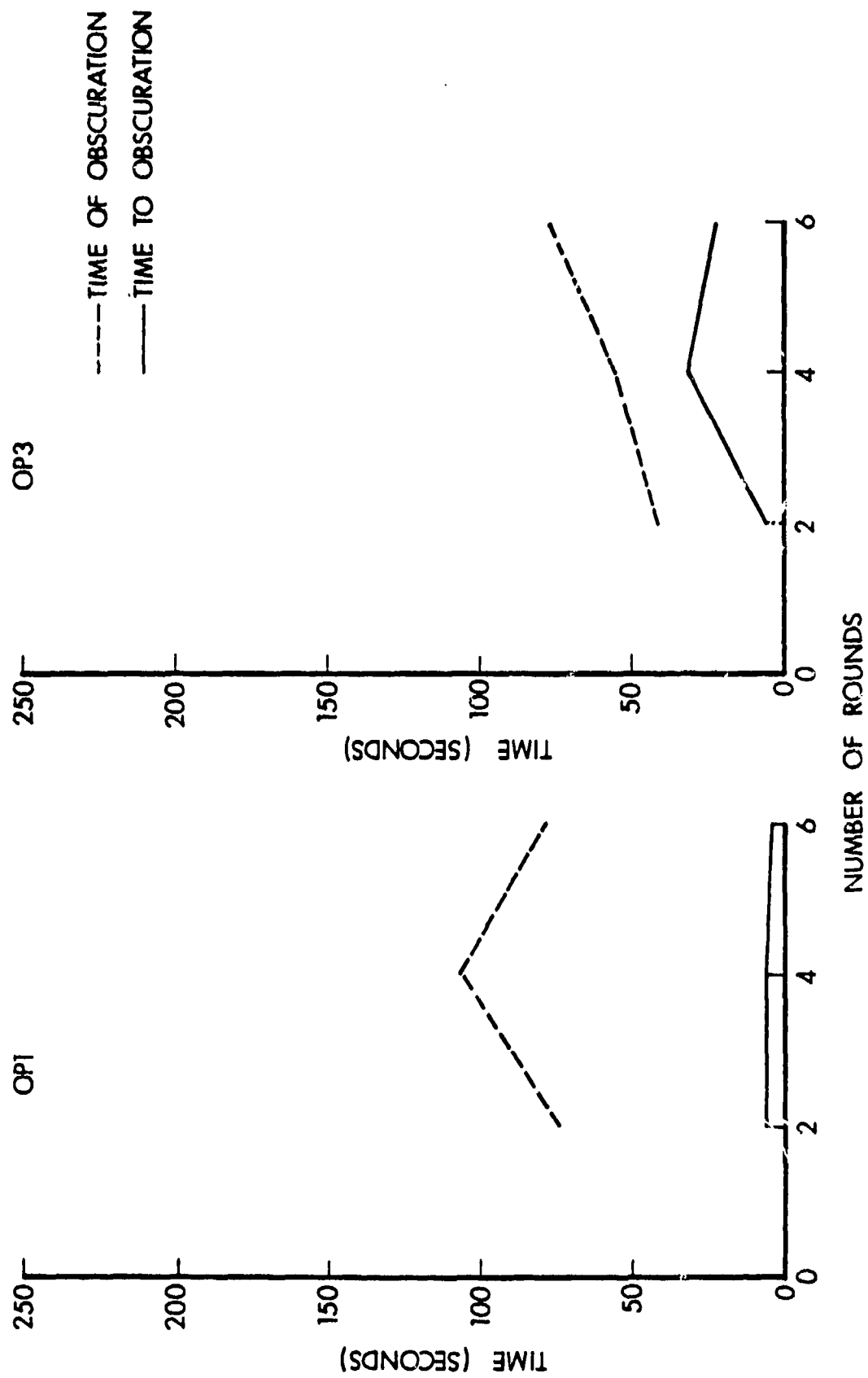


Figure 3.3a. Time to Obscuration and Time of Obscuration of the 155mm WP Smoke at OP1 and OP3.

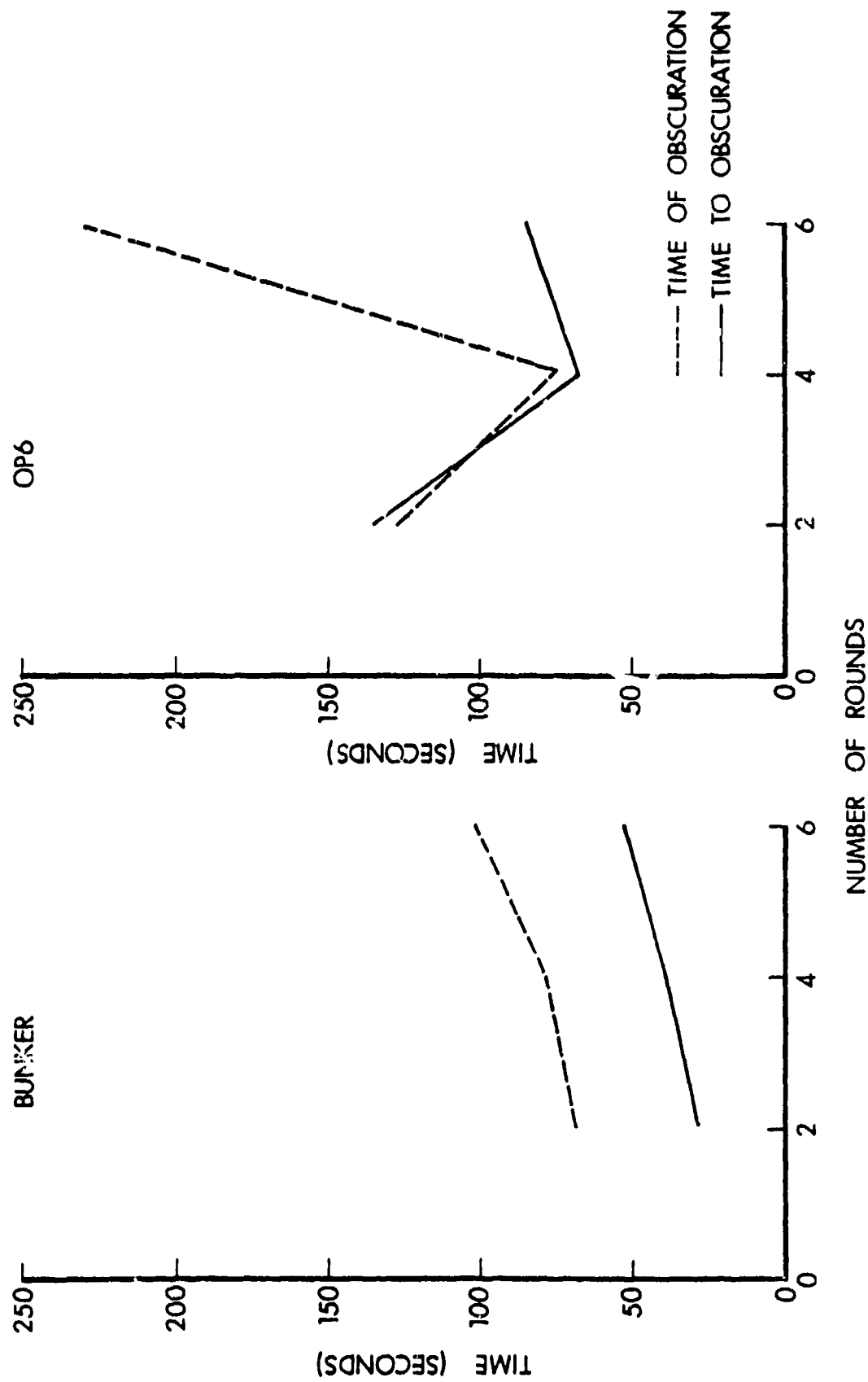


Figure 3.3b. Time to Obscuration and Time of Obscuration of the 155mm WP Smoke at the Bunker and OP6.

Figure 3.4 is another representation of the information presented in Figures 3.3a and 3.3b. In this figure, however, it is easier to see the position-to-position variation in the time to obscuration. The increase in time to obscuration going from OP1 to OP6 is due to the round impact area and the direction of the wind, as shown in Figure 3.2. As stated before, variation among the positions in the time of obscuration is not significant. The average of the 4 round missions did show a period of target obscuration common to all positions from 68 seconds to 90 seconds after impact.

The screening efficiency gives some measure of the availability of the target when smoke is present. The screening efficiency at each position for the average six round mission is shown in the table in Figure 3.2. These show that the best screening efficiency (0.94) occurred from the position upwind from the targets (OP1). This should be obvious, since the time to obscuration is very short from this position. Screening efficiency at OP6 should be lower due to the increase in the time to obscuration (0.73). Lower still, however, was the screening efficiency from the bunker (0.65). This is due primarily to the proximity of the bunker to the targets as compared to the greater distances associated with the other observer positions.

### 3.3 155MM Hexachloroethane.

Figure 3.5 shows the general location where the rounds impacted and the direction and velocity of the wind in relation to the observer positions. The wind was generally from the north and the impact area was generally north of the three targets. The smoke should obscure the targets from OP6 first, Bunker second, OP3 third, and OP1 last as the wind carries the smoke past the targets.

Figures 3.6a and 3.6b show that, in general, the time to obscuration did increase from OP6 counterclockwise to OP1, but only slightly. The analysis of variance on the time to obscuration data showed that neither the observer position nor the number of rounds fired had a significant effect on the time of obscuration at the 0.25 and 0.10 levels of significance, respectively. Although neither factor was significant, this analysis does indicate that the number of rounds fired had a greater effect on obscuration, just the opposite of the result obtained with the 155mm WP missions discussed in Section 3.2. This may be due to the difference in behavior of the two types of smoke. The WP pillars and diffuses rapidly, while the HC remains closer to the ground and diffuses slower. Thus, the higher concentration produced by the greater number of rounds should maintain a screen sufficient to obscure the targets from the observers for a longer period of time. But again, the increase in obscuration due to increasing the number of rounds fired is not statistically significant. The tendency of the 155mm HC to maintain a uniform screen also accounts for non-variability due to the observer position.

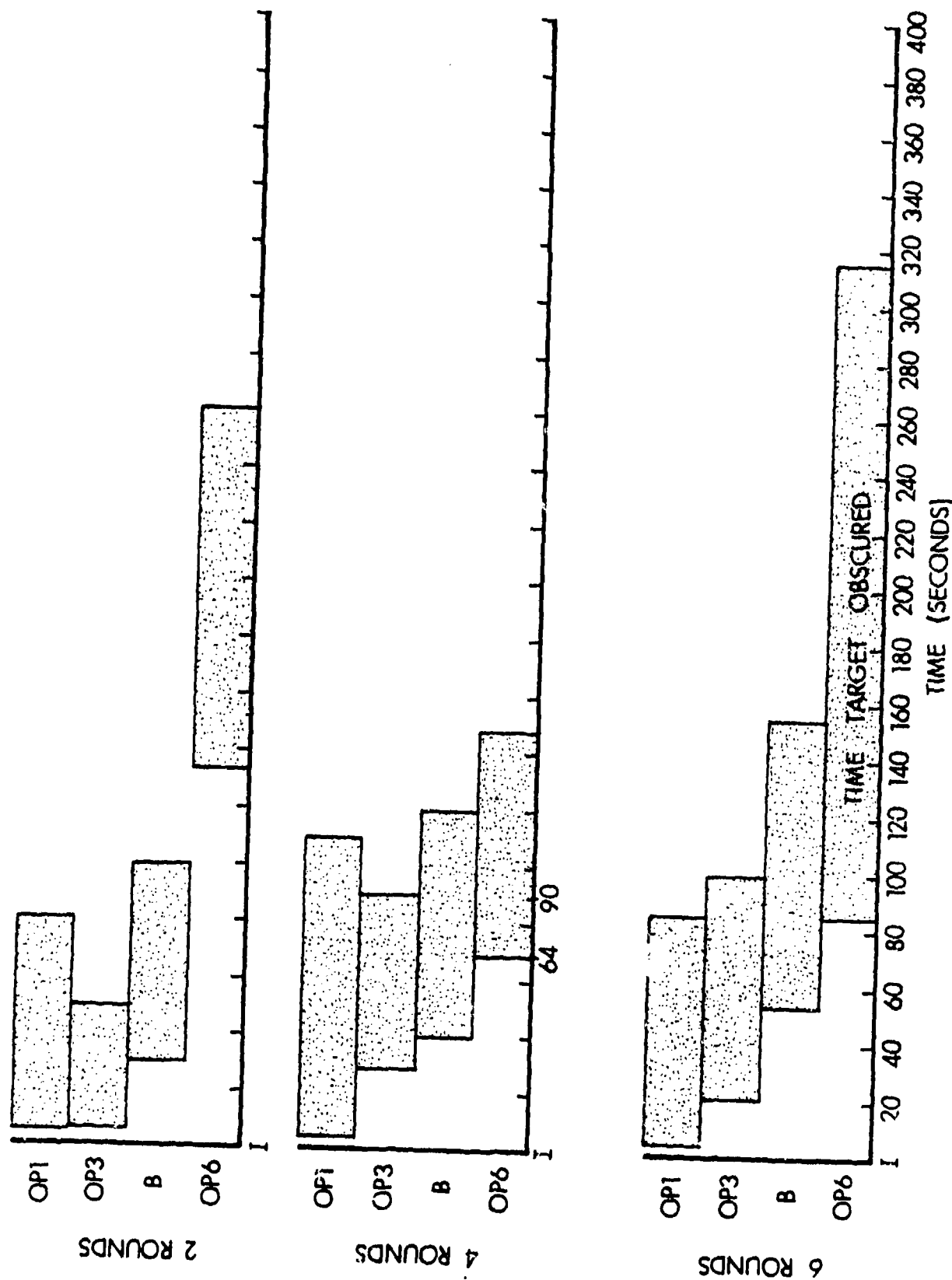
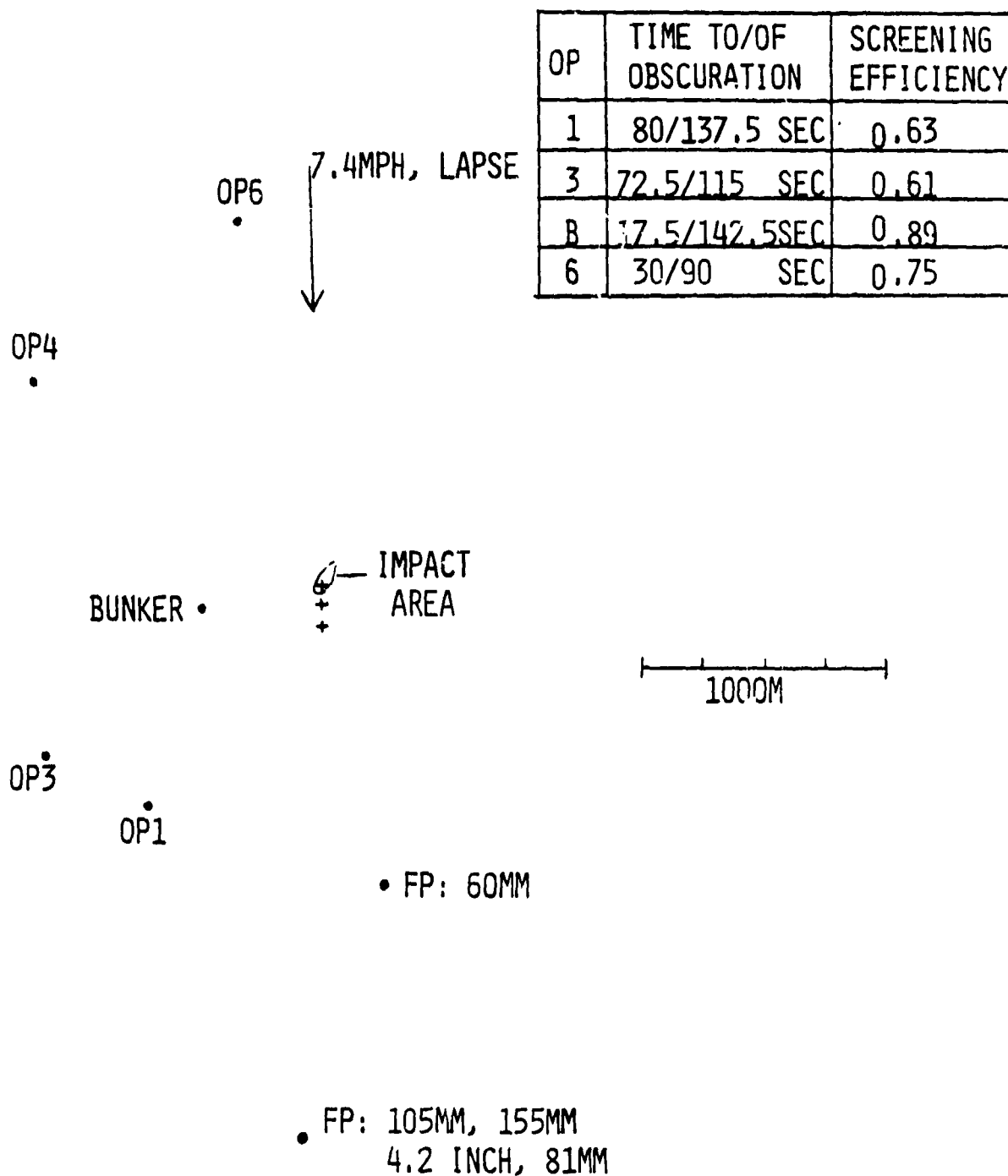


Figure 3.4 Time History of the Target Obscuration due to the 155 mm WP Smoke from OP1, OP3, Bunker and OP6.



**FIGURE 3.5.** WIND CONDITIONS AND ROUND IMPACT AREA OF THE 155MM HC SMOKE IN RELATION TO OBSERVER POSITIONS. SCREENING EFFICIENCY AT EACH POSITION IS ALSO LISTED FOR THE 6 ROUND MISSIONS.



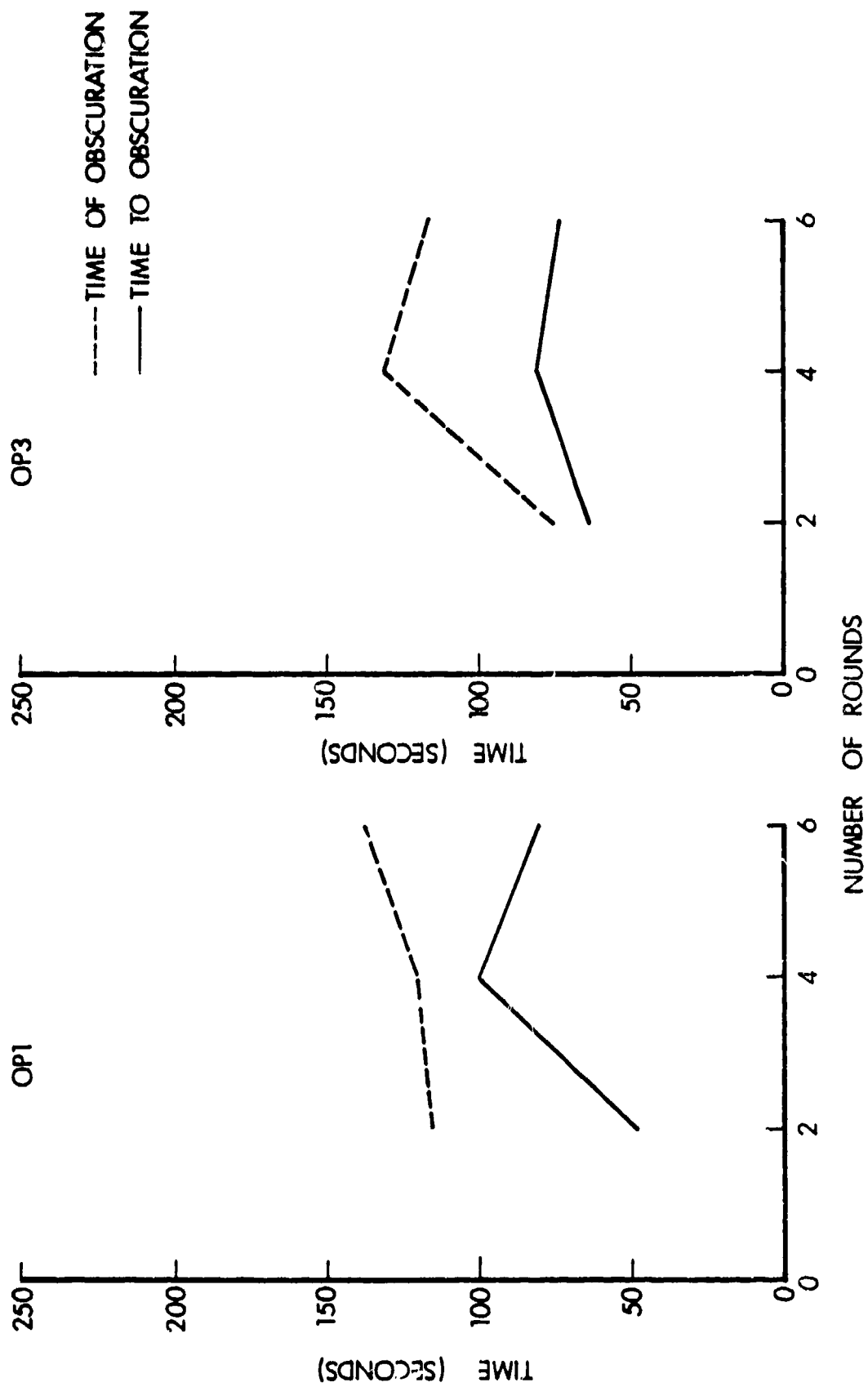


Figure 3.6a. Time to Obscuration and Time of Obscuration of the 155mm HC Smoke at OP1 and OP3.

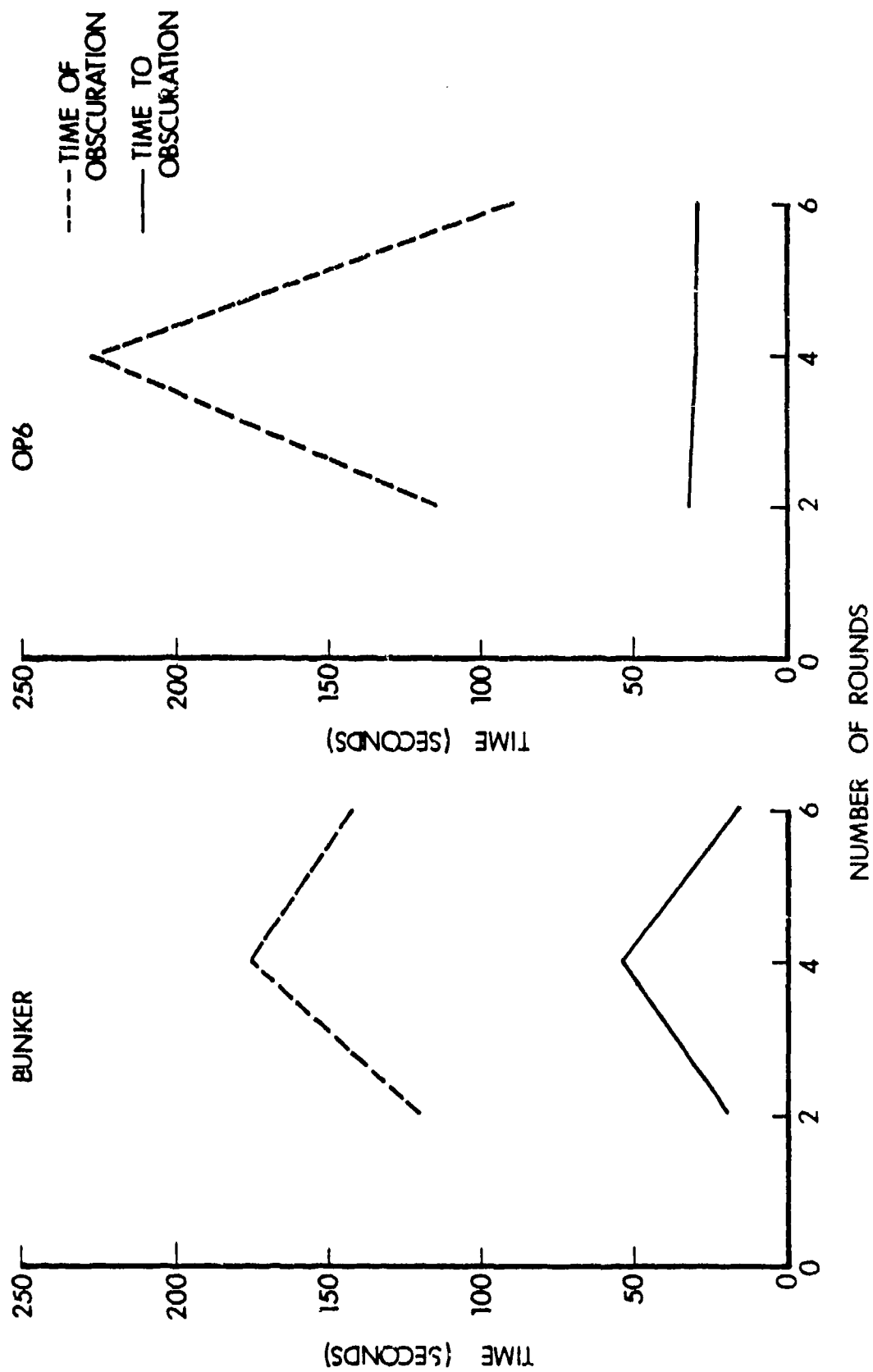


Figure 3.6b. Time to Obscuration and Time of Obscuration of the 155mm HC Smoke at the Bunker and OP6.

Figure 3.7 shows more clearly the tendency of the time to obscuration to increase going from OP6 to OP1. This increase is due to the round impact area and wind conditions as shown in Figure 3.5. It should be noted that the results shown for the 4 round firing is for a single mission which had excellent results. The 2 and 6 round missions are averages over several missions. The results are still quite representative of an actual firing situation, however. Figure 3.7 also shows periods of obscuration common to all positions. The period was from 65 to 140 seconds after impact with 2 rounds, 100 to 210 seconds with 4 rounds and 80 to 120 seconds with 6 rounds.

Logically, the screening efficiency should be highest at OP6 (where smoke build up time is short) and lowest toward OP1 and OP3 (where the smoke must drift past the targets before obscuration occurs). The bunker may also have a low screening efficiency since it is much closer to the targets. The screening efficiency results shown in the table in Figure 3.5 for the 6 round missions showed this result with the exception of the bunker. A very high screening efficiency was obtained by the bunker observer.

#### 3.4 4.2 Inch White Phosphorus.

Figure 3.8 shows the general impact location of the rounds and the direction and velocity of the wind in relation to the observer positions. The wind direction is similar to that associated with the 155mm WP missions, except, that wind velocity is greater for the 4.2 inch WP missions by a factor of approximately two. Thus, the targets should be obscured first from OP1, then OP3, the bunker, and finally OP6 as the smoke moves northward.

The 4.2 inch WP smoke behaved differently from either the 155mm WP or the 155mm HC smoke. It is characteristic of the 155mm WP to obscure rapidly but, it also pillars and diffuses rapidly. The 155mm HC takes longer to build up but lingers near the ground and remains much longer than the 155mm WP. The 4.2 inch WP behaved more like a hybrid of the other two. It built up rapidly to obscure the targets after impact and remained near the ground instead of pillaring. Its four round screening efficiency, as shown in Figure 3.8, is higher than the 155mm WP at every observer position, even though the wind velocity during the 4.2 firings was approximately twice as great.

Figures 3.9a and 3.9b show the tendency for the time of obscuration to increase as the number of rounds increases. The figures also show the tendency of the time to obscuration at the OP's to increase going clockwise around the target from OP1 to OP6. The analysis of variance of the obscuration data showed that the effect of the observer position was not significant at the 0.25 level of significance. However, the effect of the number of rounds was greater, and was not significant until the 0.05 level. This is similar to the result obtained with the 155mm HC missions. The 4.2 inch WP behaved more like HC once it had

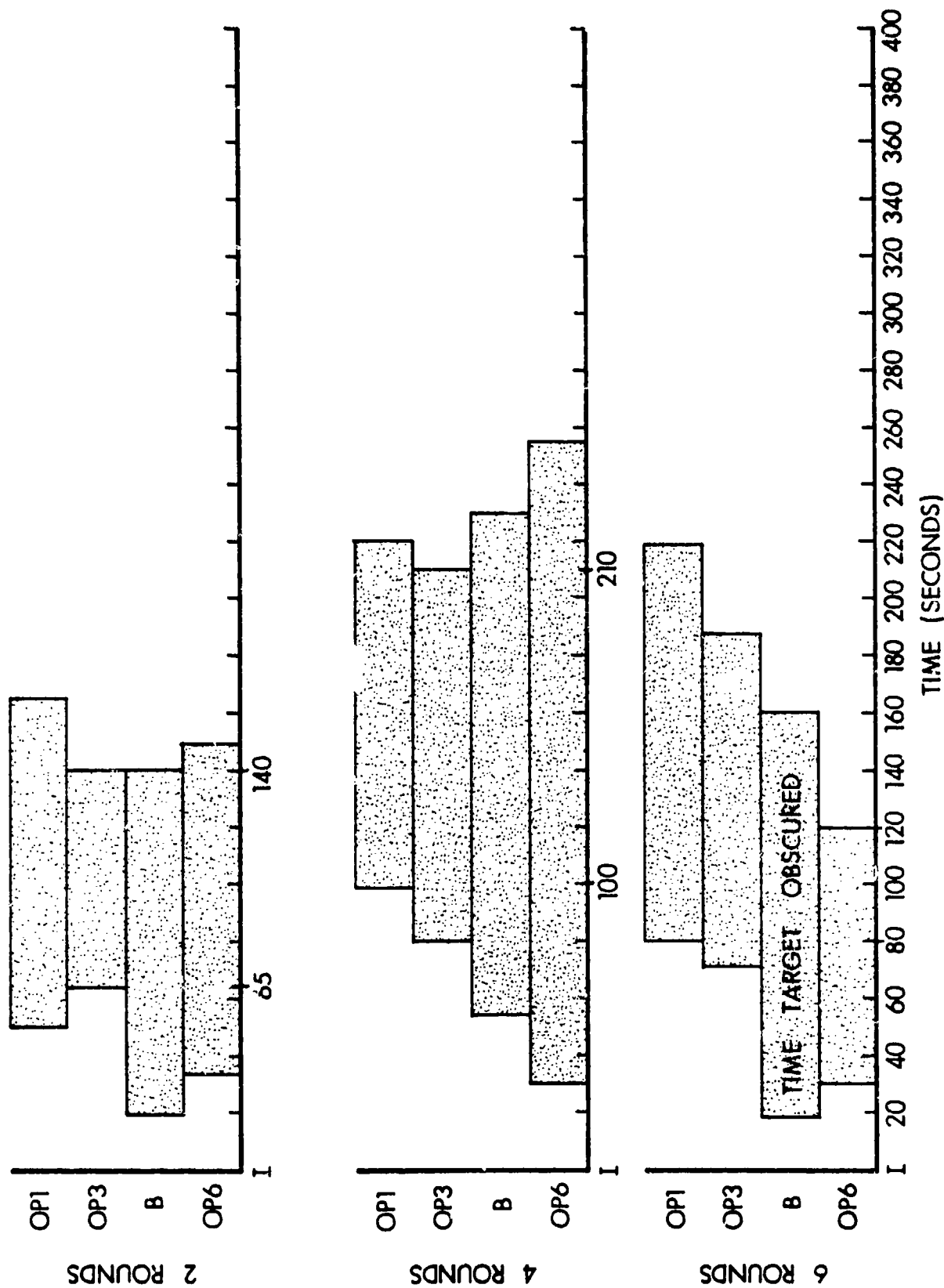


Figure 3.7 Time History of the Target Obscuration due to the 155mm HC Smoke from OP1, OP3, Bunker and OP6.

OP	TIME TO/OF OBSCURATION	SCREENING EFFICIENCY
1	5.3/112.5 SEC	0.95
3	5.8/73 SEC	0.93
B	21.4/67.5 SEC	0.76
6	35/117.5 SEC	0.77

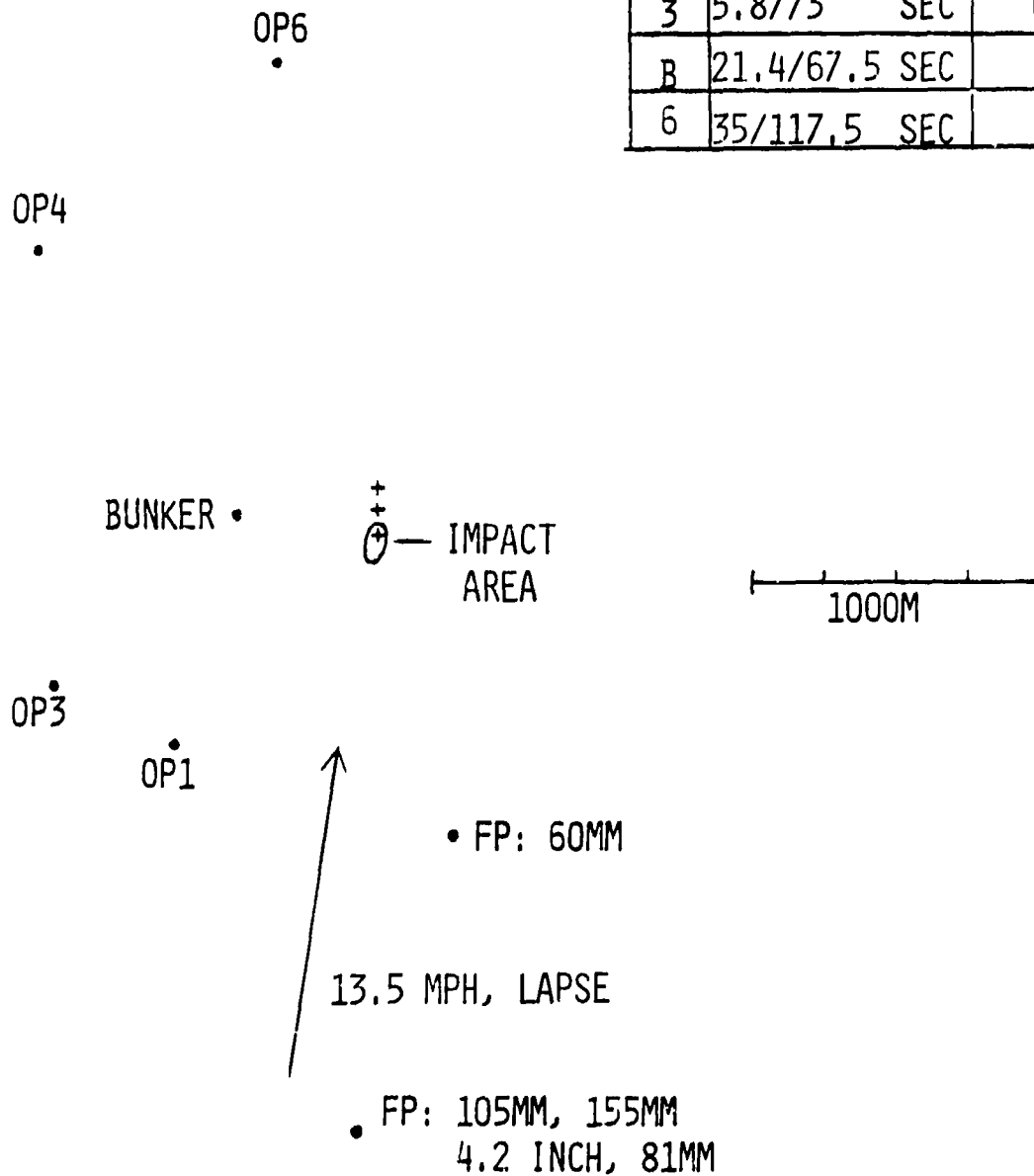


FIGURE 3.8. WIND CONDITIONS AND ROUND IMPACT AREA OF THE 4.2INCH WP SMOKE IN RELATION TO OBSERVER POSITIONS. SCREENING EFFICIENCY AT EACH POSITION IS ALSO LISTED FOR THE 4 ROUND MISSIONS.

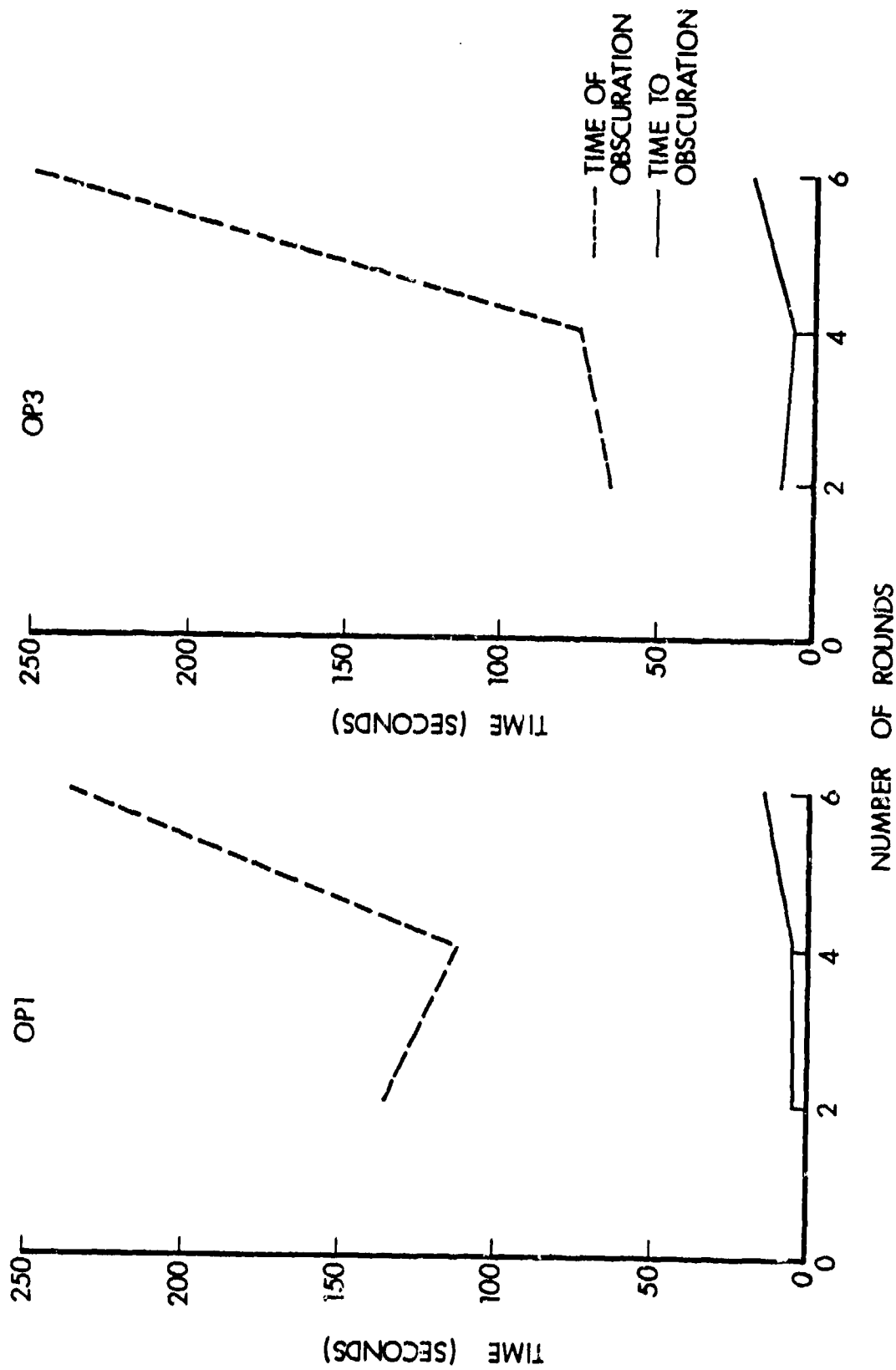


Figure 3.9a. Time to Obscuration and Time of Obscuration of the 4.2 inch WP S - ke at OP1 and OP3.

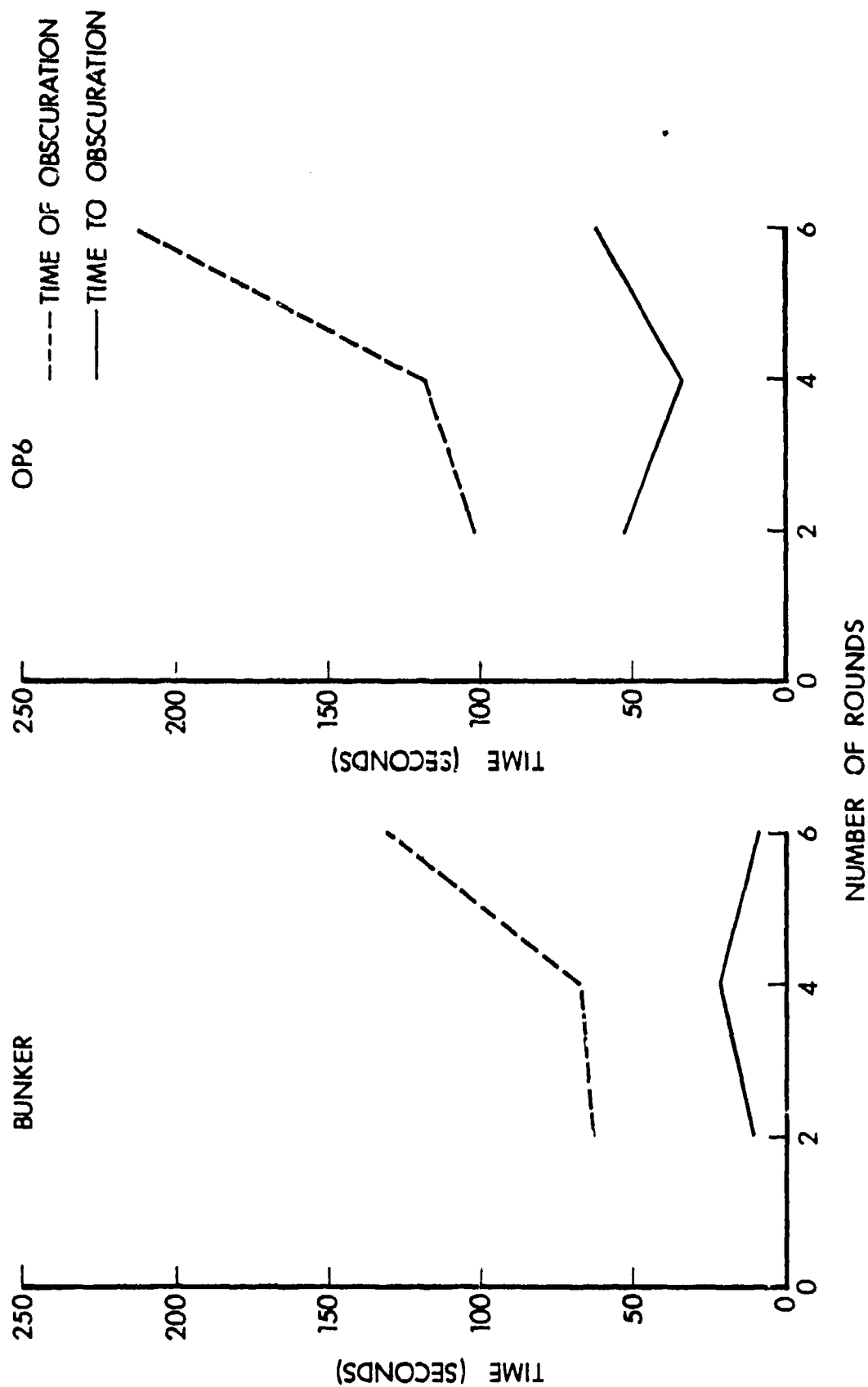


Figure 3.9b. Time to Obscuration and Time of Obscuration of the 4.2 inch WP Smoke at the Bunker and OP6.

fully built up, staying close to the ground and not pillaring. A lapse condition did exist on the days of the 4.2 inch WP missions so there was nothing preventing the smoke from pillaring, such as an inversion condition. The burst characteristics of the 4.2 inch WP smoke round are different from those of other WP smoke rounds, so this could account for the differences in behavior. This tendency for the smoke to remain near the ground producing a uniform screen could account for the non-variability of the time of obscuration among the observer positions.

Figure 3.10 shows the tendency of the time to obscuration to increase as the smoke moves from south to north, thus obscuring the targets from OP1 first and OP6 last. The results for the 6 round firing are for one mission only, whereas the 2 and 4 round firings are averages over several missions. Periods of target obscuration common to all observer positions shown in Figure 3.10 are: 55 to 75 seconds after impact for 2 rounds, 35 to 80 seconds after impact for 4 rounds, and 60 to 140 seconds for the 6 round mission.

### 3.5 105mm Hexachloroethane.

Figure 3.11 shows the general round impact area and the wind conditions. As shown, the impact area was a little too far south of the targets for the wind to carry the smoke past all the targets. The impact area was generally in line with OP1 and OP3. Thus, obscuration at these two positions should occur first. Obscuration of the targets to the bunker and OP6 may be irregular because of the poor placement of the rounds.

The screening efficiency of 6 rounds of 105mm HC, as shown in Figure 3.11, indicates that this is the case. The screening efficiency at OP1 was very good; this was followed by OP3, OP6, and the bunker. Figures 3.12a and 3.12b also show this to be true. Generally, the time to obscuration was low for OP1 and increased for OP3, OP6, and for the bunker. Excluding the 6 round mission data where a moving tank was the target, the data shown on these figures indicate that increasing the number of rounds fired does not necessarily increase the time of obscuration. With the number of rounds fired increasing from 2 to 4, the time of obscuration increased for OP1 and OP6 and decreased for OP3 and the bunker.

An analysis of variance of the time of obscuration data, both including and excluding the 6 round tank target missions, was performed. Both analyses showed that neither the observer position nor the number of rounds fired had a significant effect on the time of obscuration, even at the 0.25 level of significance. The F statistic was so low for the effect of the number of rounds that an  $\alpha$  of 0.99 could reasonably be assumed. The lack of variation in the times of obscuration due to the number of rounds could be due to the poor placement of rounds. This may also explain the non-variability due to observer position.



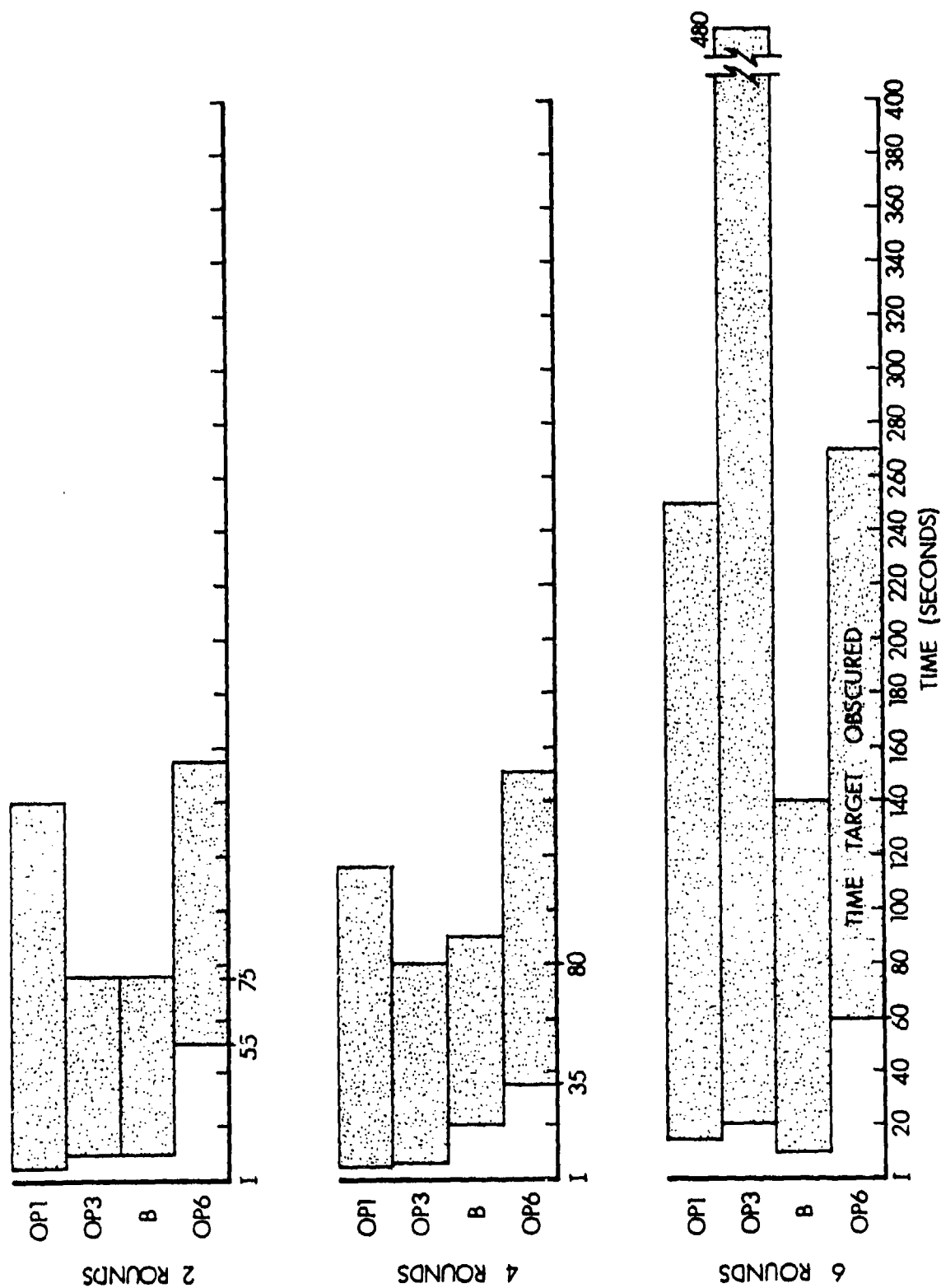


Figure 3.10 Time History of the Target Obscuration due to the 4.2 inch WP Smoke from OP1, OP3, Bunker and OP6.

OP	TIME TO/OF OBSCURATION	SCREENING EFFICIENCY
1	10/190 SEC	0.95
3	40/60 SEC	0.6
B	58.3/41.6 SEC	0.42
6	40/55 SEC	0.58

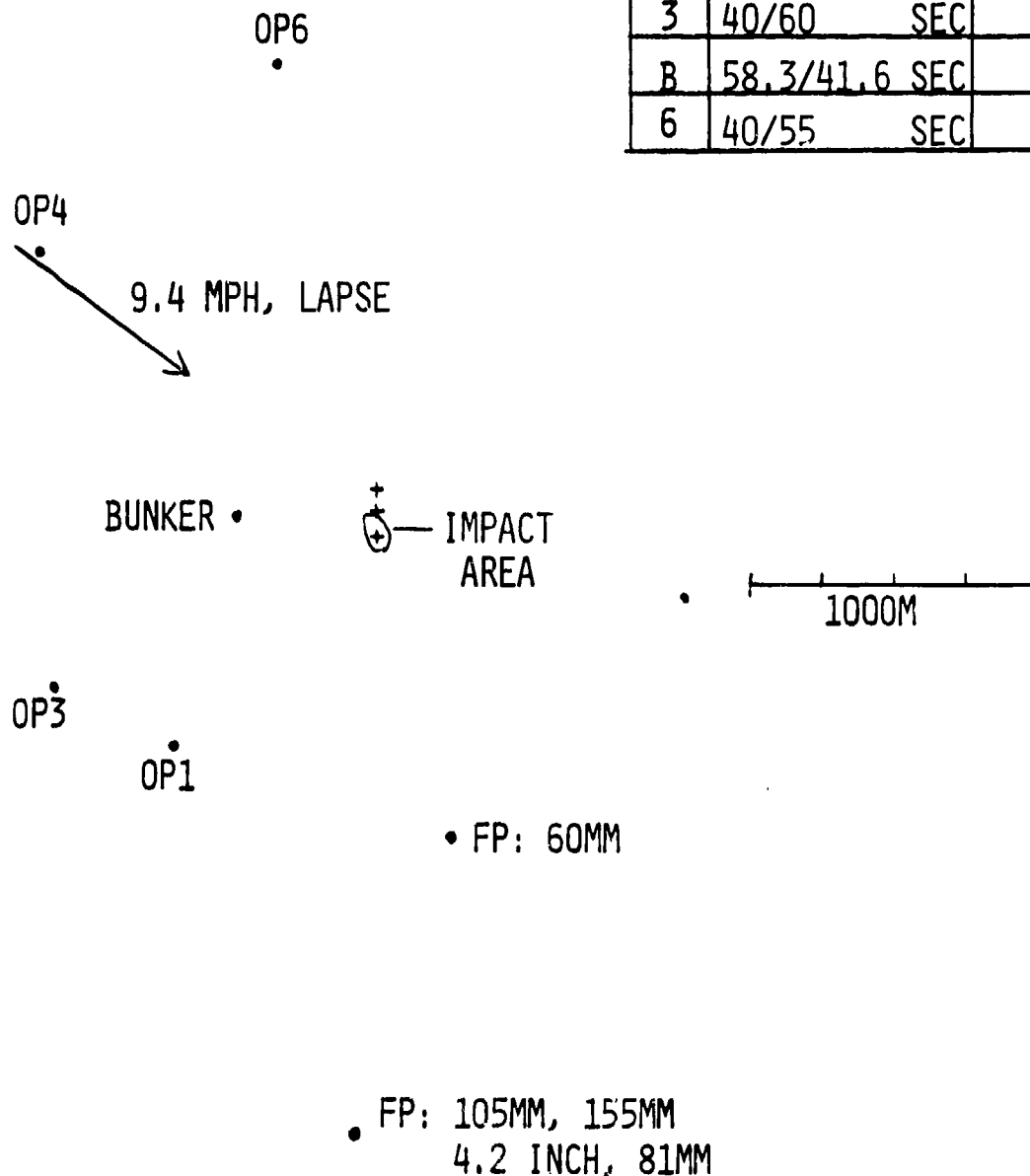


FIGURE 3.11. WIND CONDITIONS AND ROUND IMPACT AREA OF THE 105MM HC SMOKE IN RELATION TO OBSERVER POSITIONS. SCREENING EFFICIENCY AT EACH POSITION IS ALSO LISTED FOR THE 6 ROUND MISSION.

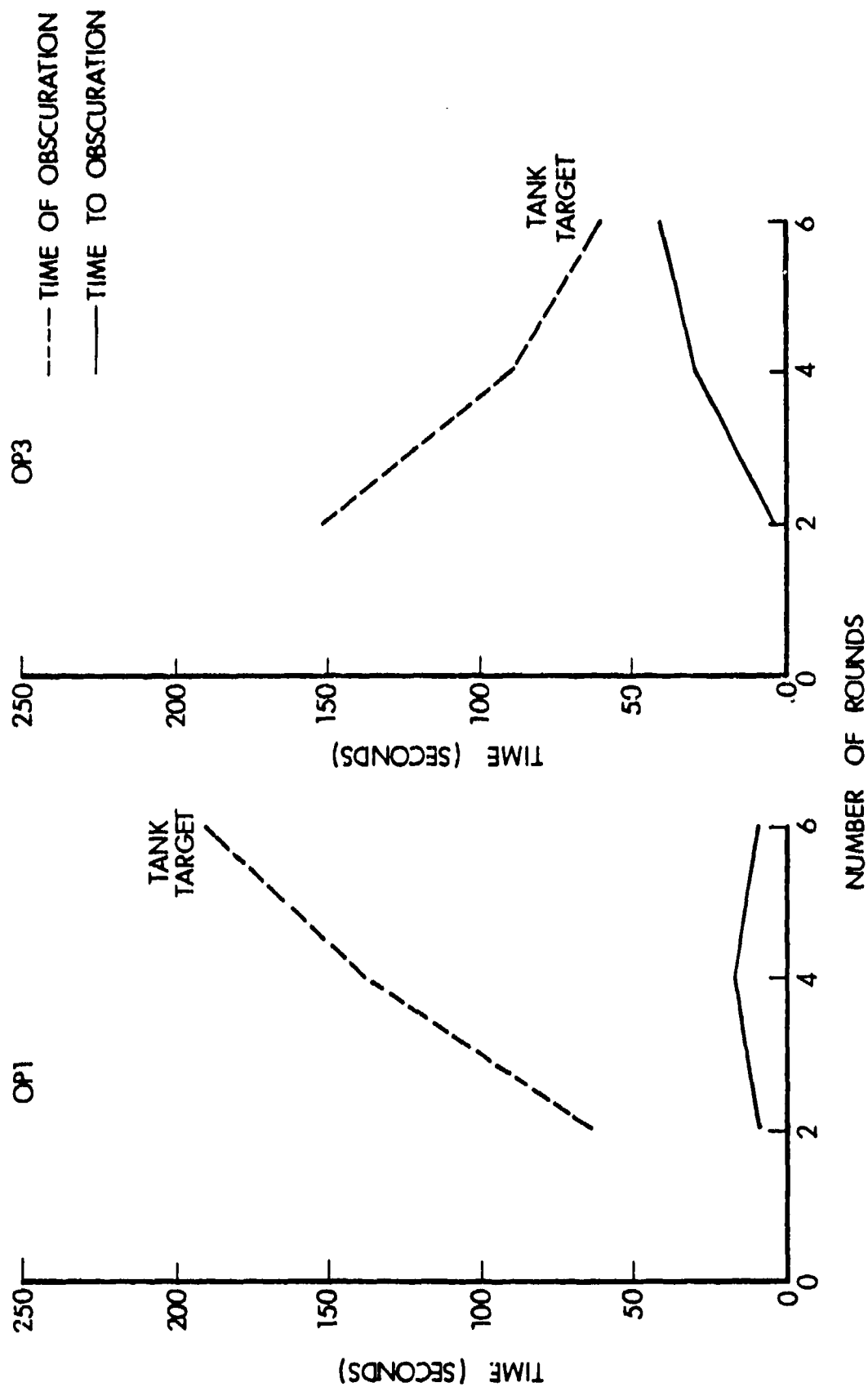


Figure 3.12a. Time to Obscuration and Time of Obscuration of the 105mm HC Smoke at OP1 and OP3.

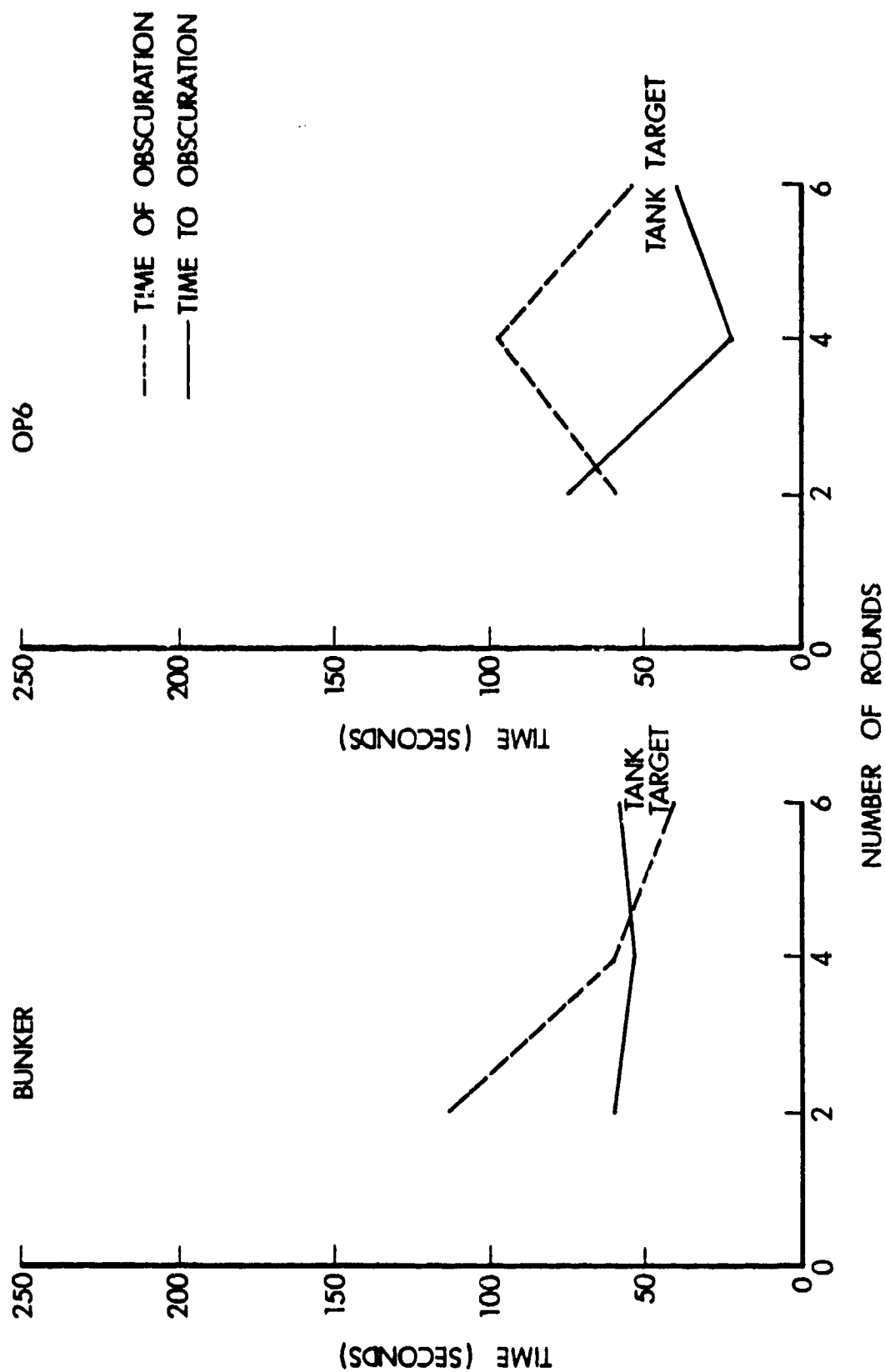


Figure 3.12b. Time to Obscuration and Time of Obscuration of the 105mm HC Smoke at the Bunker and OP6.

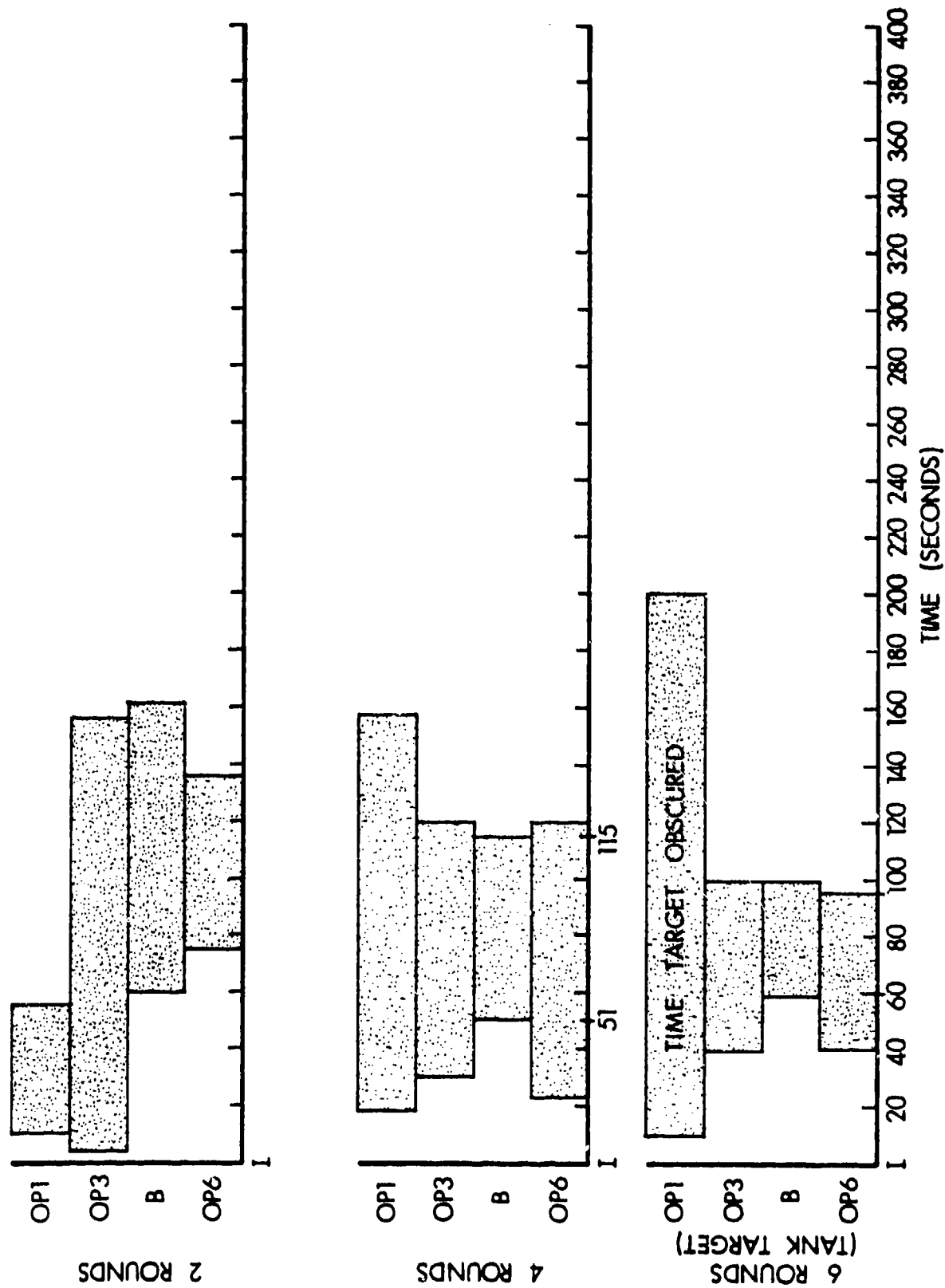


Figure 3.13 Time History of the Target Obscuration due to the 105mm HC Smoke from OP1, OP3, Bunker and OP6.

Figure 3.13 shows how the targets were obscured quickly at OP1 and OP3. It also shows the inconsistencies in the time of obscuration data, sometimes increasing and sometimes decreasing, while the number of rounds increases. Periods of target obscuration common to all observer positions were experienced from 51 to 115 seconds after impact during the average 4 round mission and 59 to 95 seconds after impact during the average 6 round mission (tank target).

### 3.6 105mm White Phosphorus.

Figure 3.14 shows the weather conditions that prevailed during the firing of the 105mm WP rounds, and also the general impact area of the 105mm WP rounds. The rounds impacted near the north target, with a few rounds impacting behind the targets. The 105mm smoke rounds exhibited a high degree of pillaring. Uniform screens were rare and short lived. Due to the behavior characteristics of this round and the poor round placement, the time of obscuration at the various observer positions may not follow any logical pattern, as was generally exhibited by the types of rounds discussed in some of the previous sections of this report.

The screening efficiency of the average 6 round 105mm WP mission is shown in the table in Figure 3.14. The highest efficiency was exhibited from OP1. In most of the missions, several rounds impacted about 100 meters in front of the north target. The smoke was blown toward the south, obscuring the center target from OP1. In several of these missions, rounds also impacted in front of and between the center and south targets. These impact points were very close to the line of sight between the center target and OP1, thus contributing to a higher screening efficiency from OP1. Due to the geometry of the test layout, impact points and wind direction, the other OP's had lower screening efficiencies than OP1.

Figures 3.15a and 3.15b show that the best obscuration occurred at the two extreme positions, OP1 and OP6. The analysis of variance showed that the effect of the observer position on the time of obscuration was not significant until the 0.10 level. The effect of the number of rounds was not significant until the 0.25 level. While neither effect was statistically significant, this analysis does support the observation made from Figures 3.15a and 3.15b that, although not highly significant statistically, the durations of obscuration were generally greater at OP1 and OP6.

Figure 3.16 shows the time history of the obscuration for the average 2, 4 and 6 round missions. No periods of obscuration common to all observer positions were observed. If round placement had been more accurate, the results might have followed a more logical sequence of obscuration. With the large amount of pillaring exhibited by this round, however, a significant improvement in obscuration abilities may only be realized with near perfect round placement.

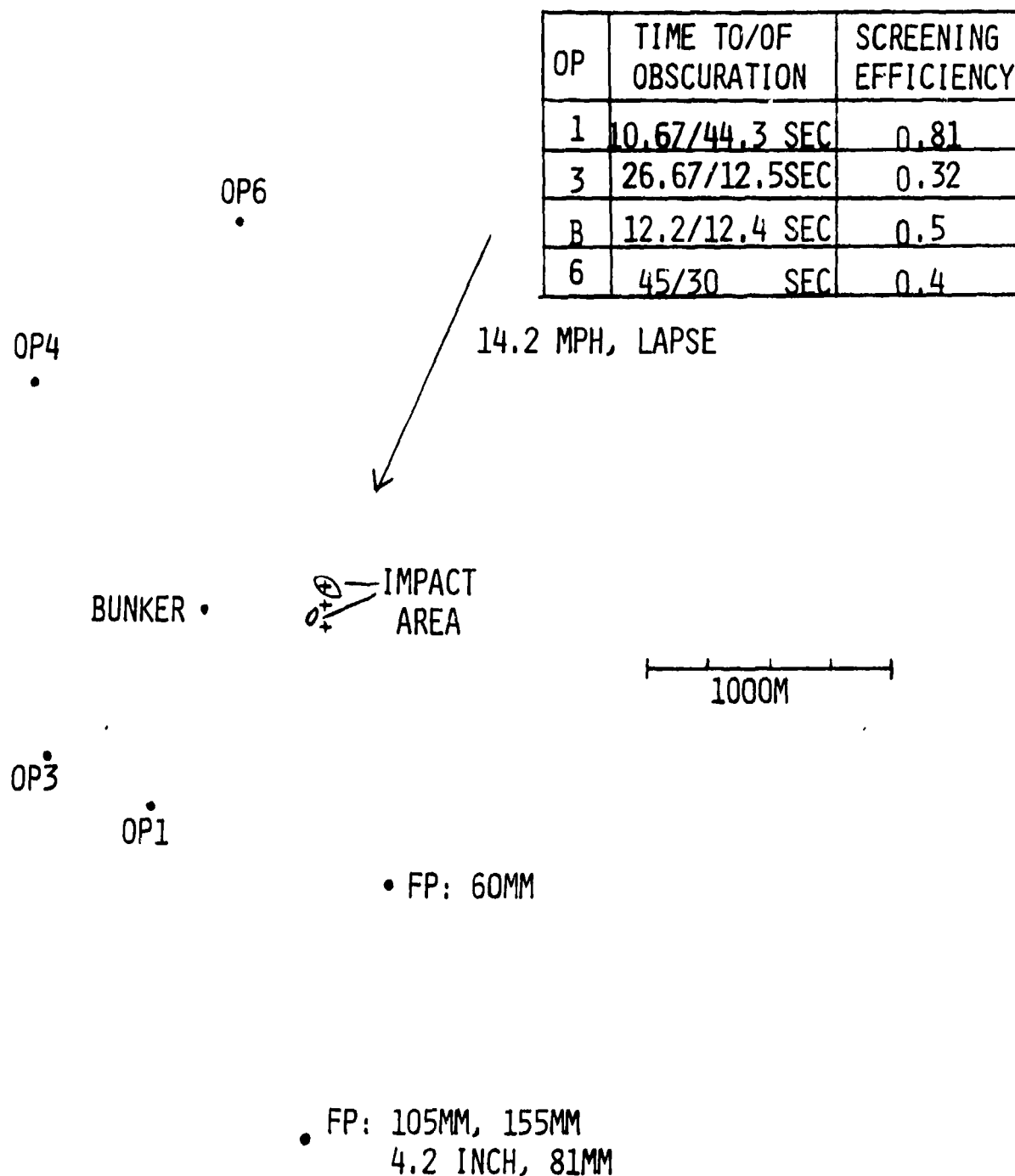


FIGURE 3.14. WIND CONDITIONS AND ROUND IMPACT AREA OF THE 105MM WP SMOKE IN RELATION TO OBSERVER POSITIONS. SCREENING EFFICIENCY AT EACH POSITION IS ALSO LISTED FOR THE 6 ROUND MISSIONS.

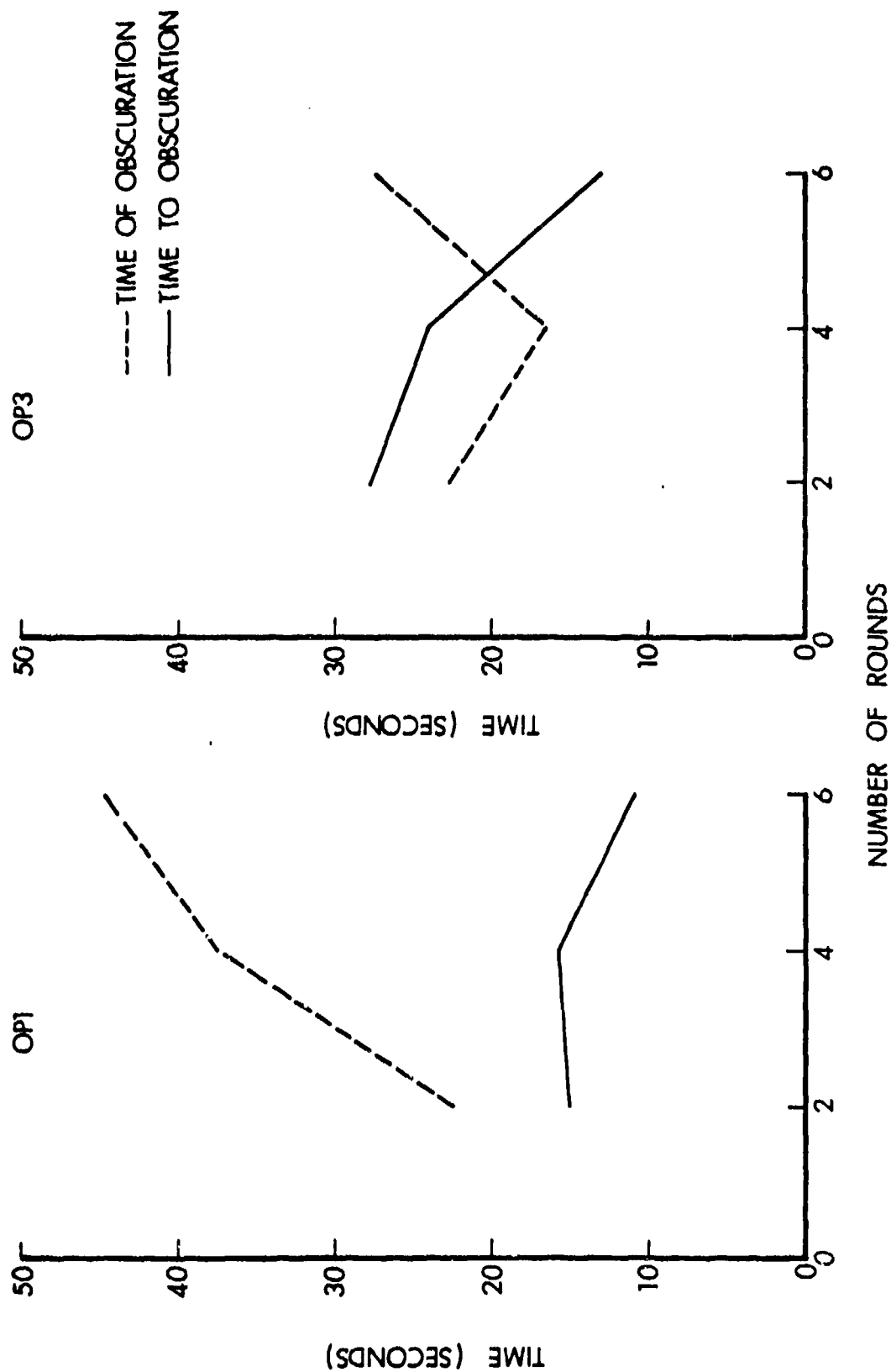


Figure 3.15a. Time to Obscuration and Time of Obscuration of the 105mm WP Smoke at OP1 and OP3.



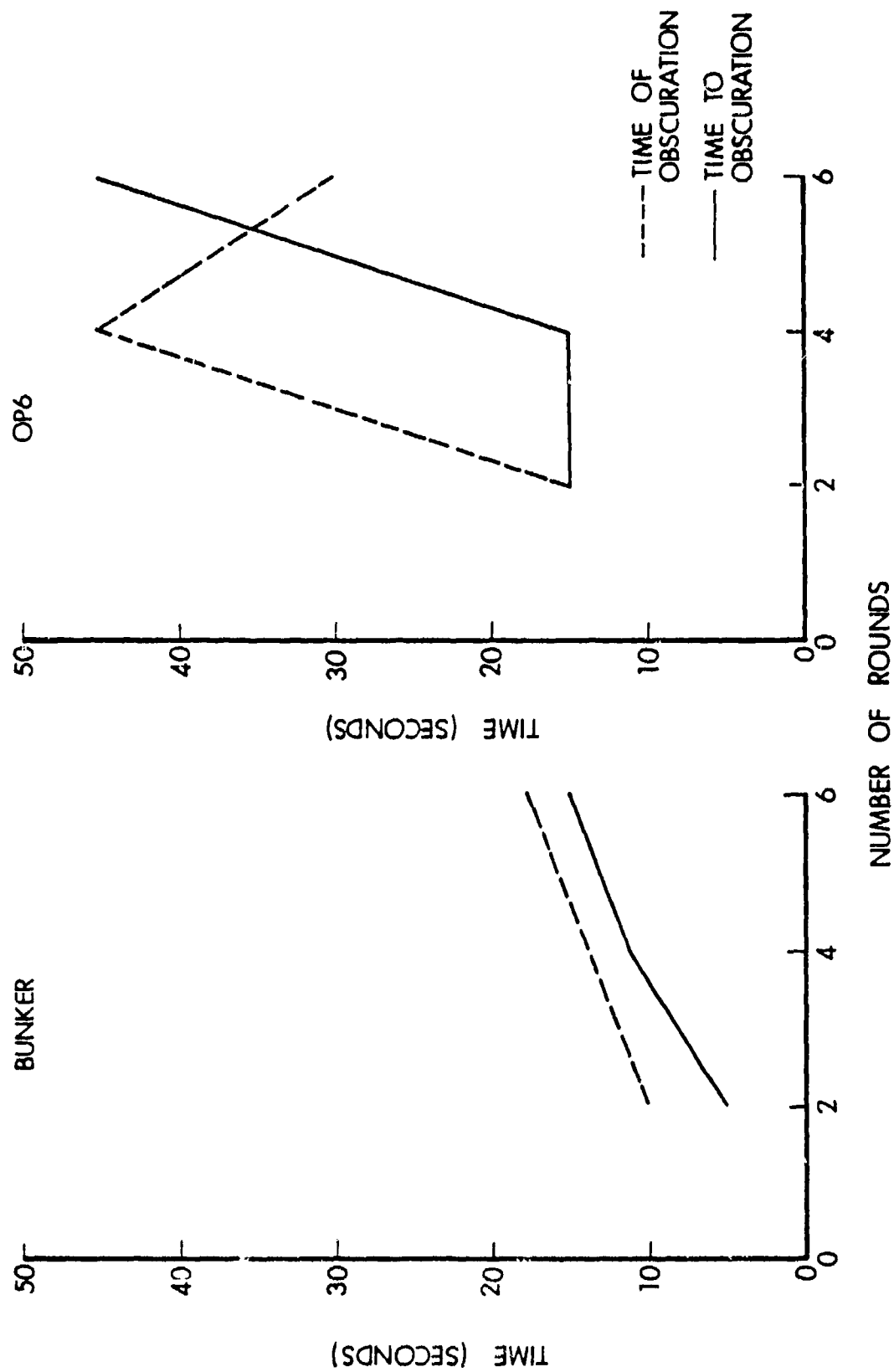


Figure 3.15b. Time to Obscuration and Time of Obscuration of the 105mm WP Smoke at the Bunker and OP6.

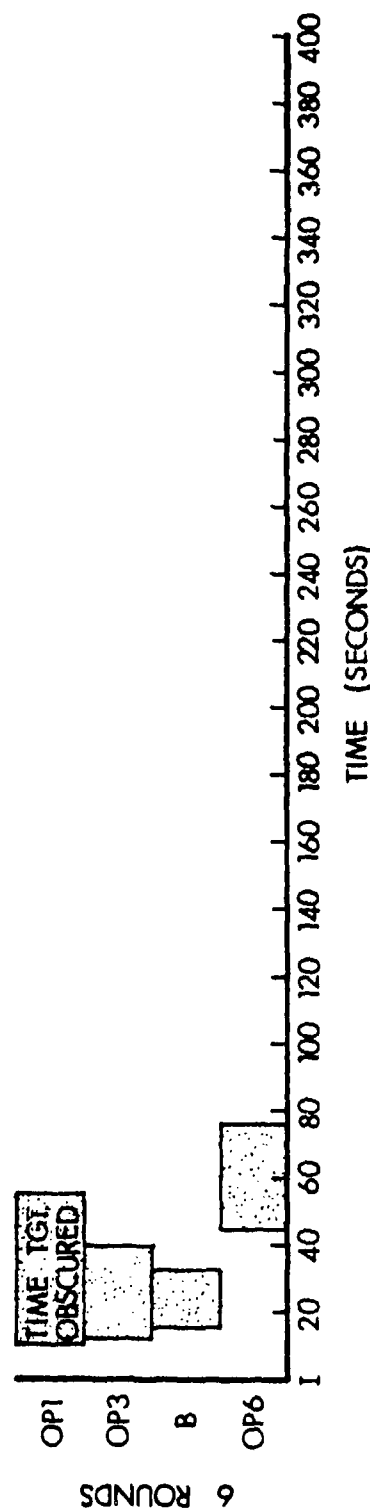
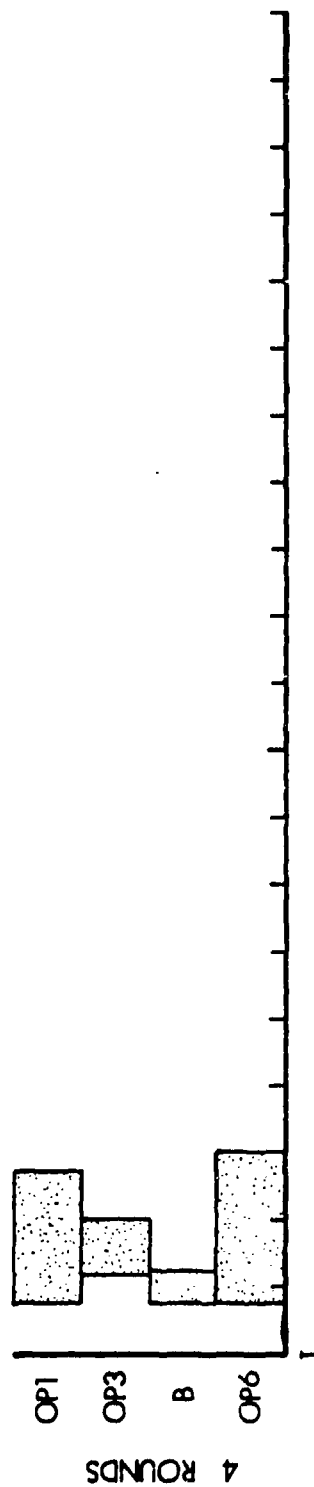
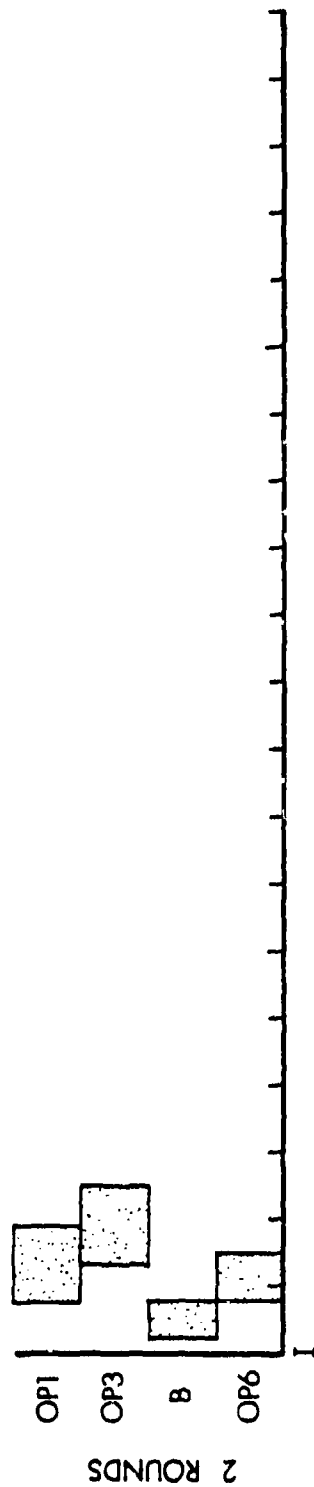


Figure 3.16 Time History of the Target Obscuration due to the 105mm WP Smoke from OP1, OP3, Bunker and OP6.

### 3.7 81mm White Phosphorus.

Figure 3.17 shows the weather conditions and round impact area that prevailed during the average 81mm firing mission. Because of the delivery accuracy, all firings were not usable; consequently, a total of only five missions provided useable data. There was some coverage of the center target, generally being obscured from the bunker first and then OP1. On the one mission where data were available from OP3, obscuration occurred there last. A large amount of pillaring occurred during the 81mm WP missions; thus, most of the smoke rose above the observer and target line of sight.

The screening efficiency of the average 3 round mission was best at the bunker and OP1. For the two missions analyzed, the rounds generally impacted about 100 meters in front of the north target. The wind blew the smoke south where the center target was obscured best from the bunker and OP1. There was no explanation from either the film or observer data as to why OP3 did not experience similar obscuration. The largest concentration of smoke occurred approximately 100 meters downwind from the impact points and not at the impact points themselves.

Figure 3.18 shows that the time of obscuration generally increased with the number of rounds fired, as did the time to obscuration. The analysis of variance showed that the number of rounds fired had no significant effect on the time of obscuration at the 0.10 level. It also showed that the observer position had even less effect on the time of obscuration, not becoming significant until the 0.25 level of significance. Figure 3.18 supports this analysis showing more effect due to the number of rounds than was due to the observer position. Neither was highly significant statistically, however.

The time history of obscuration for the one, three, and six round 81mm WP missions is shown in Figure 3.19. A period of obscuration from 15 to 40 seconds after impact common to OP1 and the bunker was observed during the single round mission. A period of obscuration from 42 to 67 seconds common to OP1, OP3, and the bunker was noted for the 3 round (platoon) missions. Both of these periods were 25 seconds long, indicating the period of time that can be expected when a target may be visually obscured from the observer by one to three rounds of 81mm WP smoke.

### 3.8 60mm White Phosphorus.

Figure 3.20 shows the prevailing meteorological conditions and round impact area during the average 60mm WP mission. The general outcome of the delivery accuracy did not produce effective smoke screens for all missions. Consequently, all the missions fired were not used in this analysis. The 60mm WP rounds pillared above the impact point which caused holes in the smoke screen, so the multiple round missions did not produce effective smoke screens. The smoke from rounds impacting in front of the targets was sometimes blown back toward the



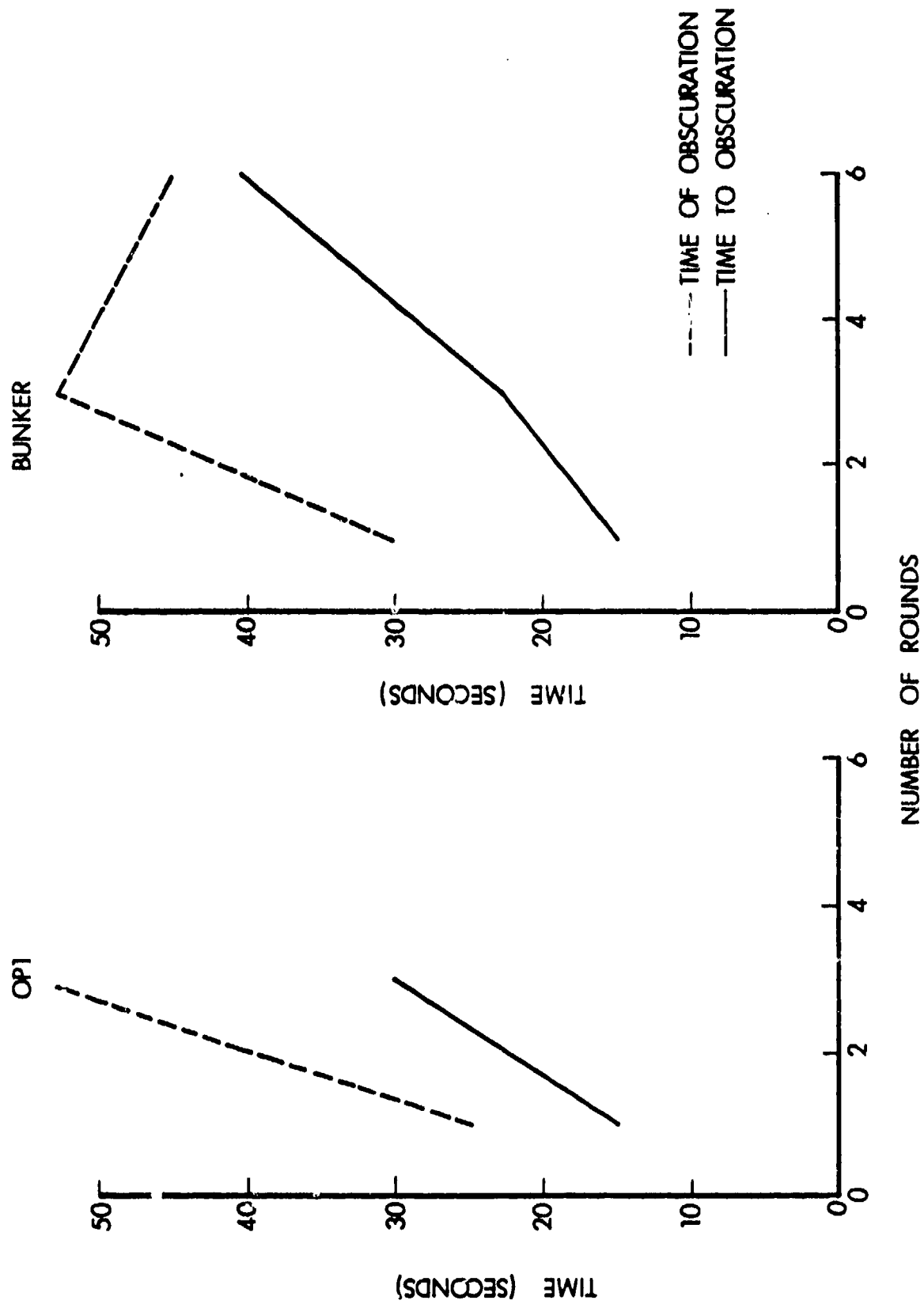


Figure 3.18 Time to Obscuration and Time of Obscuration of the 81mm WP Smoke at OP1 and the Bunker.

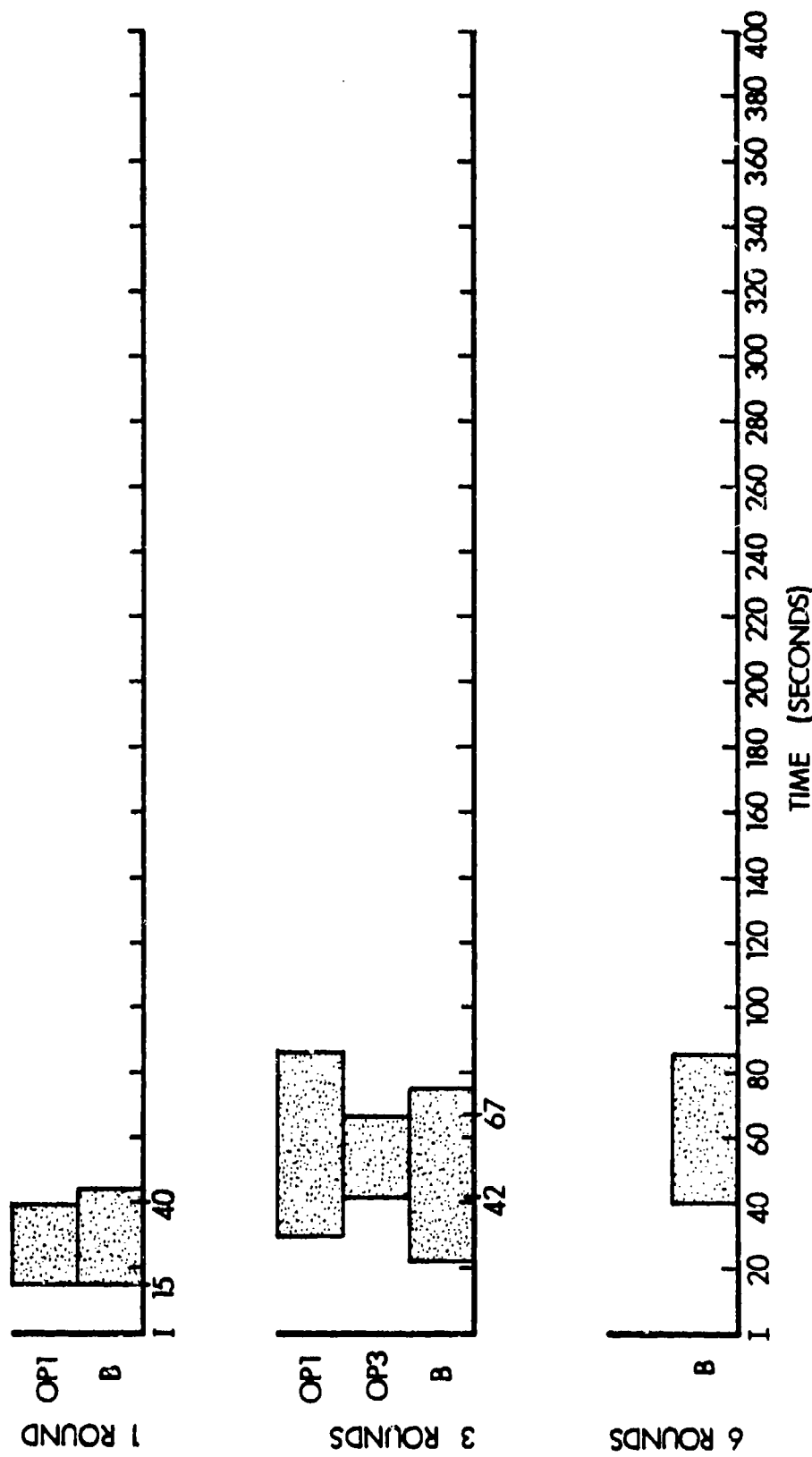
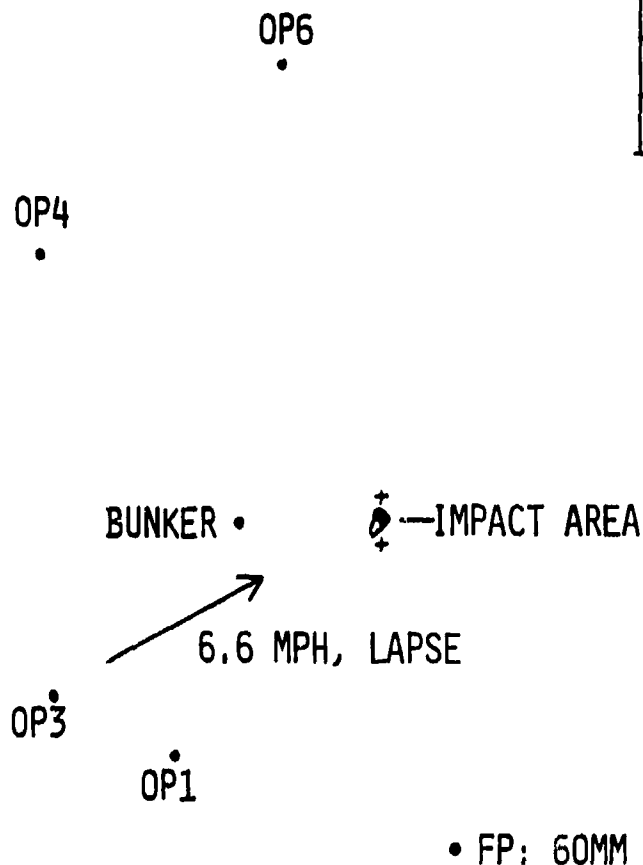


Figure 3.19 Time History of the Target Obscuration due to the 81mm WP Smoke from OP1, OP3, and the Bunker.

OP	TIME TO/OF OBSCURATION	SCREENING EFFICIENCY
1	9.5/15.5 SEC	0.62
3	NO DATA	-
B	8.3/15 SEC	0.64
6	15/15 SEC	0.5



• FP: 105MM, 155MM  
4.2 INCH, 81MM

**FIGURE 3.20.** WIND CONDITIONS AND ROUND IMPACT AREA OF THE 60MM WP SMOKE IN RELATION TO THE OBSERVER POSITIONS. SCREENING EFFICIENCY AT EACH POSITION IS ALSO LISTED FOR THE 3 ROUND MISSIONS.

target. However, no increase in obscuration time was observed for the various observer positions. Usually, obscuration only occurred when a round impacted near the line of sight.

The screening efficiency of the average 3 round mission was fair for the amount of time the smoke was present. The smoke built up quickly but diffused quickly also.

Figures 3.21a and 3.21b show the time to obscuration and time of obscuration of the 60mm WP missions studied. Generally, the time of obscuration increased as the number of rounds fired increased. The analysis of variance showed that neither the number of rounds fired nor the observer position had a highly significant effect on the time of obscuration but were more significant statistically during these missions than during most of the other calibre firings. The observer position was a significant factor until the 0.10 level and the number of rounds fired was significant until the 0.05 level. At these levels, these two factors were no longer significant. This does show, however, that the position of the observer did not affect the time of target obscuration as much as the number of rounds fired.

The time history of obscuration for the one, three, and six round 60mm WP missions for each observer position is shown in Figure 3.22. As shown, the single round mission provided very little smoke and was essentially ineffective. The three round missions were an improvement, with a period of obscuration common to all observers from 15 to 23 seconds after impact. The six round missions showed more improvement, with an increase in the time of obscuration and a common period of obscuration from 20 to 25 seconds after impact. Removing the OP3 data which are based on only one mission, the common period of obscuration increases to 16 seconds, being obscured from 15 to 31 seconds after impact. This further supports the analysis showing that the effect of the number of rounds was more significant than the position of the observer on the amount of target obscuration obtained.

### 3.9 Comparison of Obscurations for the Various Types of Smoke Rounds.

A comparison of the effects of the types of rounds from each observer position is not necessarily plausible, because the problem is confounded by varying wind conditions and round impact areas for each type of smoke round fired. Since the bunker was directly in front of the three targets, and since the line of sight was generally perpendicular to the formation of the smoke clouds, the bunker was chosen as the position where a reasonable comparison may be performed. The average time of obscuration at the bunker for each type of round is shown in Table 3.2.  $T_j$  and  $T_i$  are summations of the average time of obscuration, for the type of round and the number of rounds, respectively.  $T..$  is the summation of all the averages. These values are used in calculating the values in the ANOVA table. Although Table 3.2 shows differences in the time of obscuration for the various factors, the ANOVA will determine if either factor significantly affects the time of obscuration.



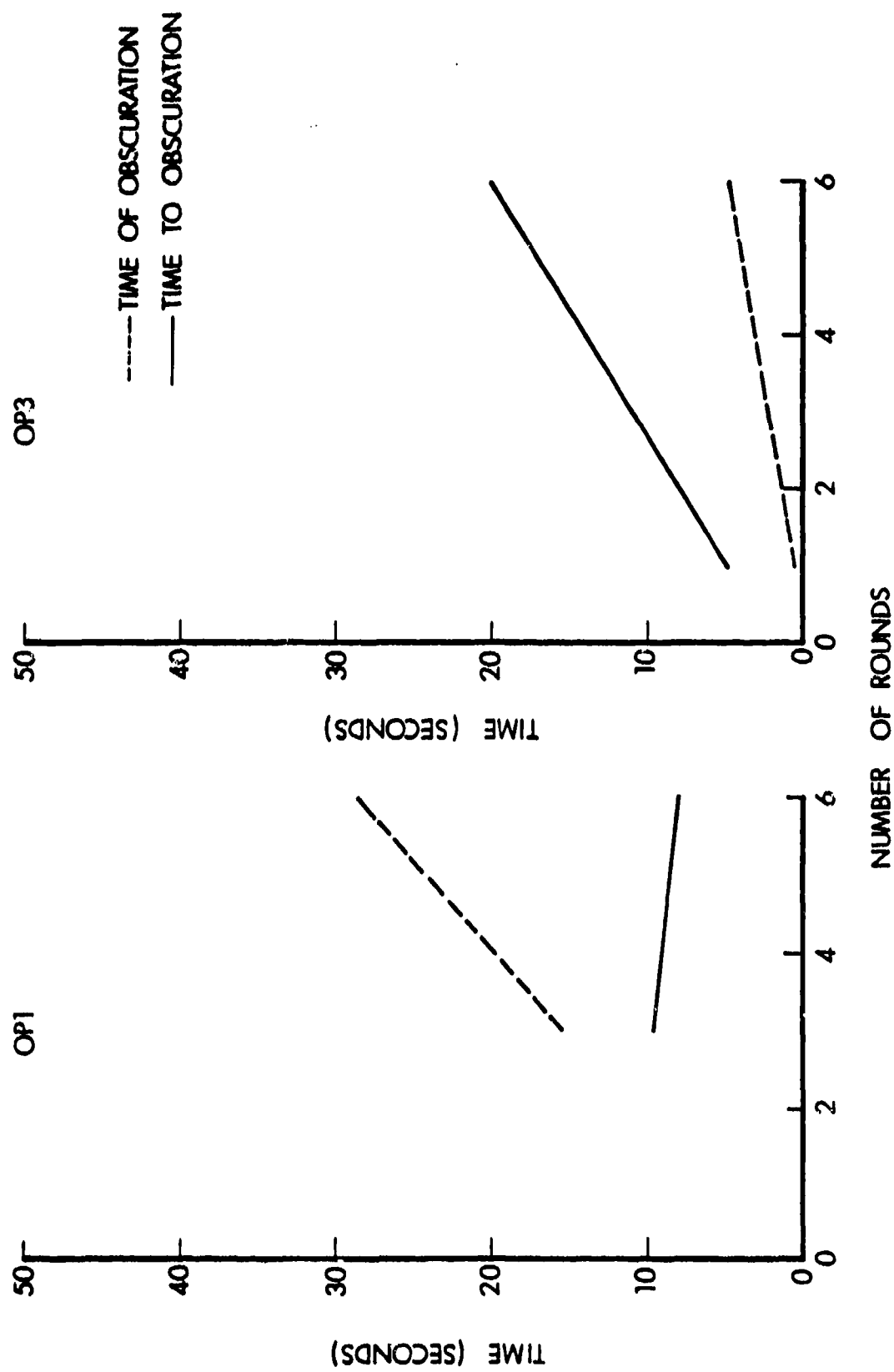


Figure 3.21a. Time to Obscuration and Time of Obscuration of the 60mm WP Smoke at OP1 and OP3.

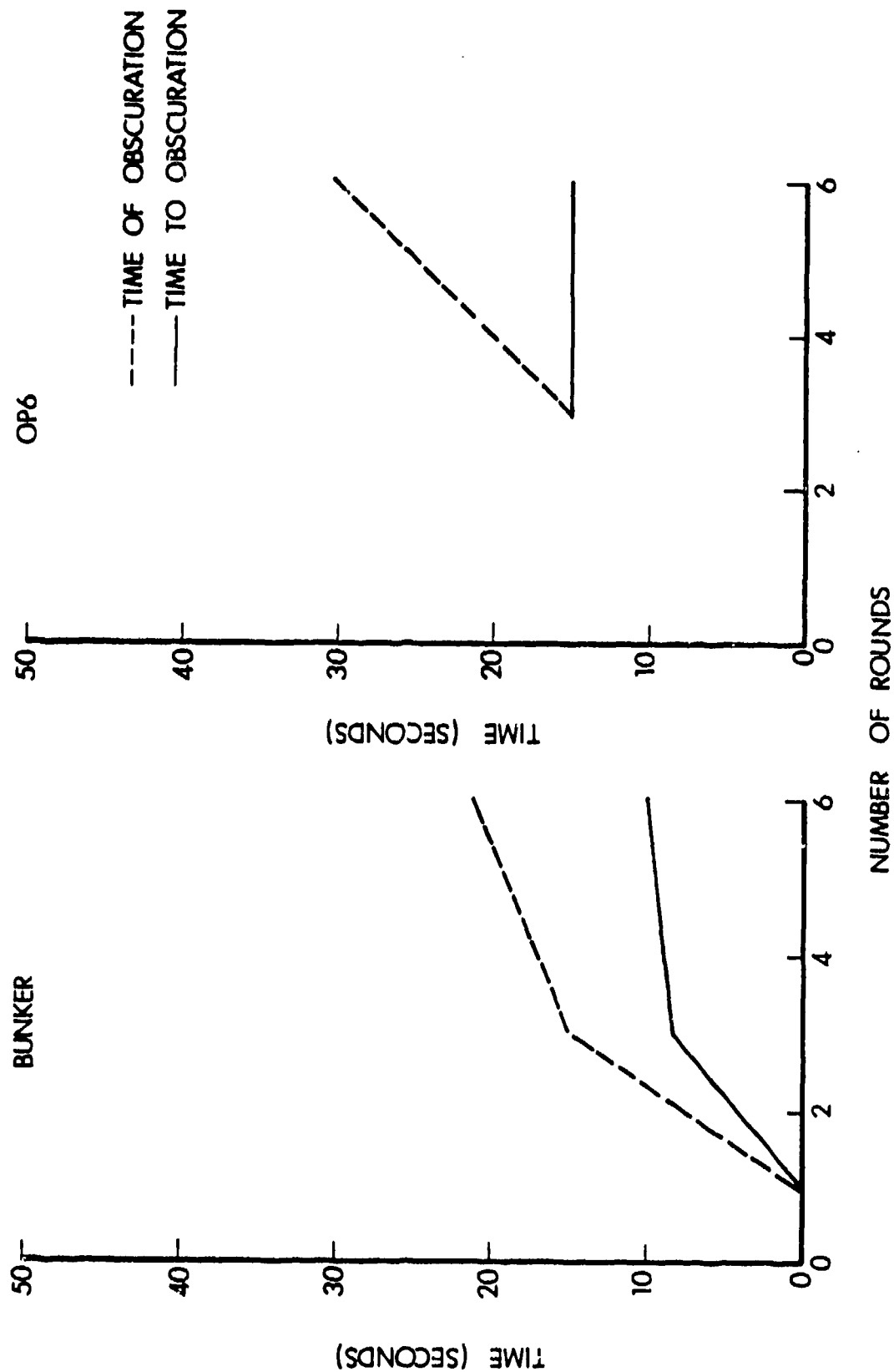


Figure 3.21b. Time to Obscuration and Time of Observation of the 60mm WP Smoke at the Bunker and OP6.

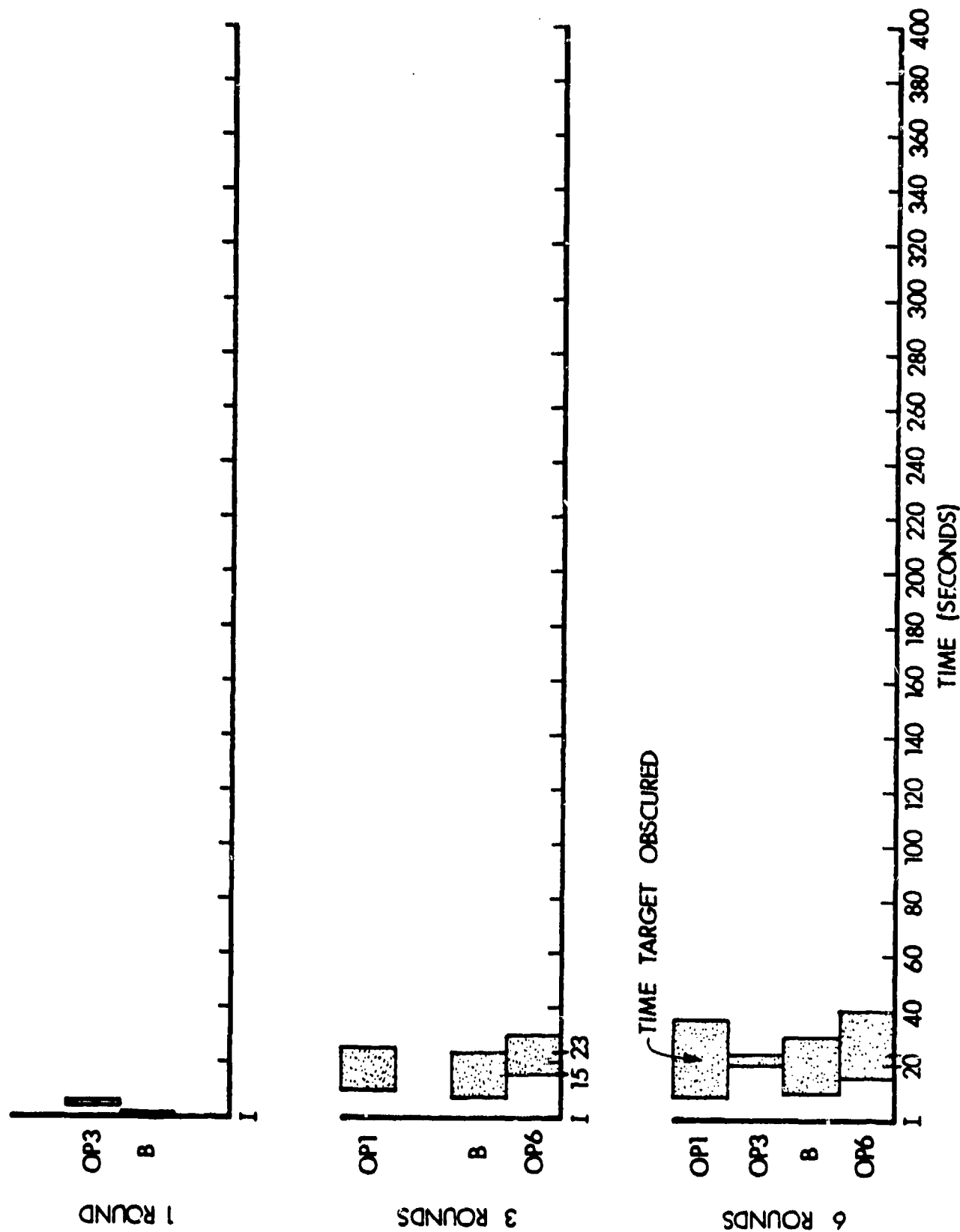


Figure 3.22 Time History of the Target Obscuration due to the 60mm WP Smoke from OP1, OP3, Bunker and OP6.

TABLE 3.2 Time of Obscuration (Seconds) for Each Type of Round as Determined at the Bunker. (\*=Tank Target)

Number of Rounds	155WP	155HC	4.2WP	105HC	105WP	81WP	60WP	T <sub>i.</sub>
1,2	70	121.5	63.75	112.5	10	30	0	407.75
3,4	80	175	67.5	60	13.75	52.5	15	463.75
6	102	142.5	130	41.6*	17.5	45	21.25	419.85
T <sub>j</sub>	252	439	261.25	214.1	41.25	127.5	36.25	1371.35
								T <sub>..</sub>

The ANOVA table for these data is shown in Table 3.3. The table shows that there is no significant difference at the 0.25 level ( $F_{.25,2,12}=1.56$ ) due to the number of rounds fired. The effect of the type of round, however, was highly significant. It was significant up to the .001 level ( $F_{.001,6,12}=12.97$ ).

TABLE 3.3 ANOVA for the Bunker Data.

Source	df	SS	MS	F
Between treatments	20	48305.33		
Type of round	6	40309.99	6718.33	10.92
Number of rounds	2	615.32	307.66	0.5
Error	12	7380.02	615	

Since the ANOVA shows that there are significant differences in the effects due to the types of rounds, it is desirable to investigate further the means of the types of rounds. The Newman-Keuls range test can be applied to examine these effects (Reference 1). The 0.05 level of significance was used in this test. The mean times of obscuration ( $\bar{Y}_{.j}$ ) are arranged in order of magnitude as follows:

	155HC	4.2WP	155WP	105HC	81WP	105WP	60WP
T <sub>j</sub>	439	261.25	252	214.1	127.5	41.25	36.25
$\bar{Y}_{.j}$	146.333	87.083	84	71.367	42.5	13.75	12.083
	(1)	(2)	(3)	(4)	(5)	(6)	(7)

The numbers in parentheses are used later in the test to refer to the types of rounds being compared in the range test; for example, 155HC is (1), 4.2WP is (2), etc.

The standard error of a treatment (type of round) mean is

$$s\bar{y}_{\cdot j} = \sqrt{\frac{615}{7}} = 9.37$$

The tabled ranges,  $z_{p,12}(.05)$ , for  $p = 2, 3, \dots, 7$ , are,

$$z_{2,12}(.05) = 3.08$$

$$z_{3,12}(.05) = 3.77$$

$$z_{4,12}(.05) = 4.2$$

$$z_{5,12}(.05) = 4.51$$

$$z_{6,12}(.05) = 4.75$$

$$z_{7,12}(.05) = 4.95$$

and the least significant ranges for this example are,

$$R_2 = (9.37)(3.08) = 28.9$$

$$R_3 = (9.37)(3.77) = 35.3$$

$$R_4 = (9.37)(4.2) = 39.4$$

$$R_5 = (9.37)(4.51) = 42.3$$

$$R_6 = (9.37)(4.75) = 44.5$$

$$R_7 = (9.37)(4.95) = 46.4$$

Testing the calibre averages,

$$(1)-(2) = 59.2 > 28.9^*$$

$$(1)-(3) = 62.3 > 35.3^*$$

$$(1)-(4) = 75.0 > 39.4^*$$

$$(1)-(5) = 103.8 > 42.3^*$$

$$(1)-(6) = 132.6 > 44.5^*$$

$$(1)-(7) = 134.2 > 46.4^*$$

$$(2)-(3) = 3.1 < 28.9$$

$$(2)-(4) = 15.7 < 35.3$$

$$(2)-(5) = 44.6 > 39.4^*$$

$$(2)-(6) = 73.3 > 42.3^*$$

$$\begin{aligned}
(2)-(7) &= 75.0 > 44.5* \\
(3)-(4) &= 12.6 < 28.9 \\
(3)-(5) &= 41.5 > 35.3* \\
(3)-(6) &= 70.2 > 39.4* \\
(3)-(7) &= 71.9 > 42.3* \\
(4)-(5) &= 28.9 = 28.9 \text{ (borderline)} \\
(4)-(6) &= 57.6 > 35.3* \\
(4)-(7) &= 59.3 > 39.4* \\
(5)-(6) &= 28.7 < 28.9 \text{ (borderline)} \\
(5)-(7) &= 30.4 < 35.3 \\
(6)-(7) &= 1.7 < 28.9
\end{aligned}$$

where the asterisk indicates significance at the 0.05 level. This shows that the 155mm HC smoke is significantly better than all the other types of smoke rounds. The 4.2 inch WP and 155mm WP were significantly better than the 81mm WP, 105mm WP, and 60mm WP. There was no significant difference between the 4.2 inch WP and the 155mm WP. The 105mm HC was significantly better than the 105mm WP and the 60mm WP.

Since the observation positions and the number of rounds fired did not significantly affect the time of obscuration at the 0.05 level of significance, the obscuration data can be combined. As previously discussed, most (50 percent) treatments were not significant at the 0.25 level and 38 percent were not significant at the 0.10 level. By combining the data, an average time to obscuration and time of obscuration for each type of smoke round can be obtained for one to six rounds fired. The distribution of observation times associated with each type of round was found to be random for the sample of distributions tested. The average ( $\mu$ ) and the sample standard deviation (S) for each type of round tested is shown in Table 3.4. In the second and third columns of the table, the first number refers to the time to obscuration, and the second refers to the time of obscuration, both in seconds.

TABLE 3.4 Mean ( $\mu$ ) and Sample Standard Deviation (S)  
of the Combined Data for Each Type of Round.

Type Round	Mean Time (Seconds) to Obscure/Obscured	Sample Standard Deviation (Seconds) to Obscure/Obscured
155 HC	45.5/120	29/42.2
4.2 WP	19.6/107.1	22/86.2
155 WP	38.5/101.3	41.6/73.5
105 HC	37.1/93.5	29.7/75.7
81 WP	28.4/41.3	12.2/13.6
105 WP	17.2/22.9	11.7/14.6
60 WP	9.8/17.9	7/15.7

The results shown in Table 3.4 follow the same pattern exhibited by the DRAGON IR track line and dayscope data examined in AMSAA Technical Report 183. This report showed that, in general, the time of obscuration from the most to the least obscuration was in the following order for the average six round missions (DRAGON dayscope): 155mm HC, 4.2 inch WP, 155mm WP, 105mm HC, 81mm WP, 105mm WP, and 60mm WP. The same order of obscuration was shown by the IR track link, with the 155mm WP and 105mm HC interchanged. However, the 4.2 inch WP, 155mm WP, and 105mm HC exhibited similar capabilities, with the associated obscuration times being very close. As shown in the Newman-Keuls range test, there were no significant differences in the obscuration capabilities of these three types of rounds at the 0.05 level of significance. The biggest difference occurred in the time to obscuration after round impact. The 4.2 inch WP build-up time was about half that associated with the 155mm WP and the 105mm HC smoke rounds.

Figure 3.23 shows the data presented in Table 3.4 graphically. In this way, one is more readily able to perceive the behavior of the smoke. This chart shows the average time to and time of obscuration for each type of smoke round. The standard deviation is recorded beside each bar on the graph as  $\pm S$ . This graph should be useful to personnel in the field. To use this chart, the dividing line between the build-up time and the obscuration time is taken as the time of impact. Going left from this line will give the time from impact to obscuration. For example, the mean build-up time for the 4.2 inch WP is about 20 seconds with a 20 second standard deviation. Going right from the dividing line shows the time of obscuration. In this example, the mean time of obscuration is approximately 107 seconds with an 86 second standard deviation. The average times ( $\bar{x}$ ) shown give an indication of the type of smoke required to accomplish a mission during moderate wind conditions, average firing accuracy, and good observer location in relation to the target and smoke cloud. The longer ( $\bar{x} + S$ ) time to obscuration together with the shorter ( $\bar{x} - S$ ) time of obscuration indicate the manner in which the smoke may behave under adverse meteorological conditions, inaccurate round placement, and poor observer location in relation to the target and smoke cloud. The shorter ( $\bar{x} - S$ ) time to obscuration together with the longer ( $\bar{x} + S$ ) time of obscuration indicate the smoke behavior which may be expected if there are favorable wind conditions and excellent round placement in relation to the target and observer. Considering the large number of variables present when dynamically firing smoke, the results presented above should not be taken as absolute, but as an indication of the kinds of results which may be expected when firing smoke. As indicated in Figure 3.23, results can vary considerably.

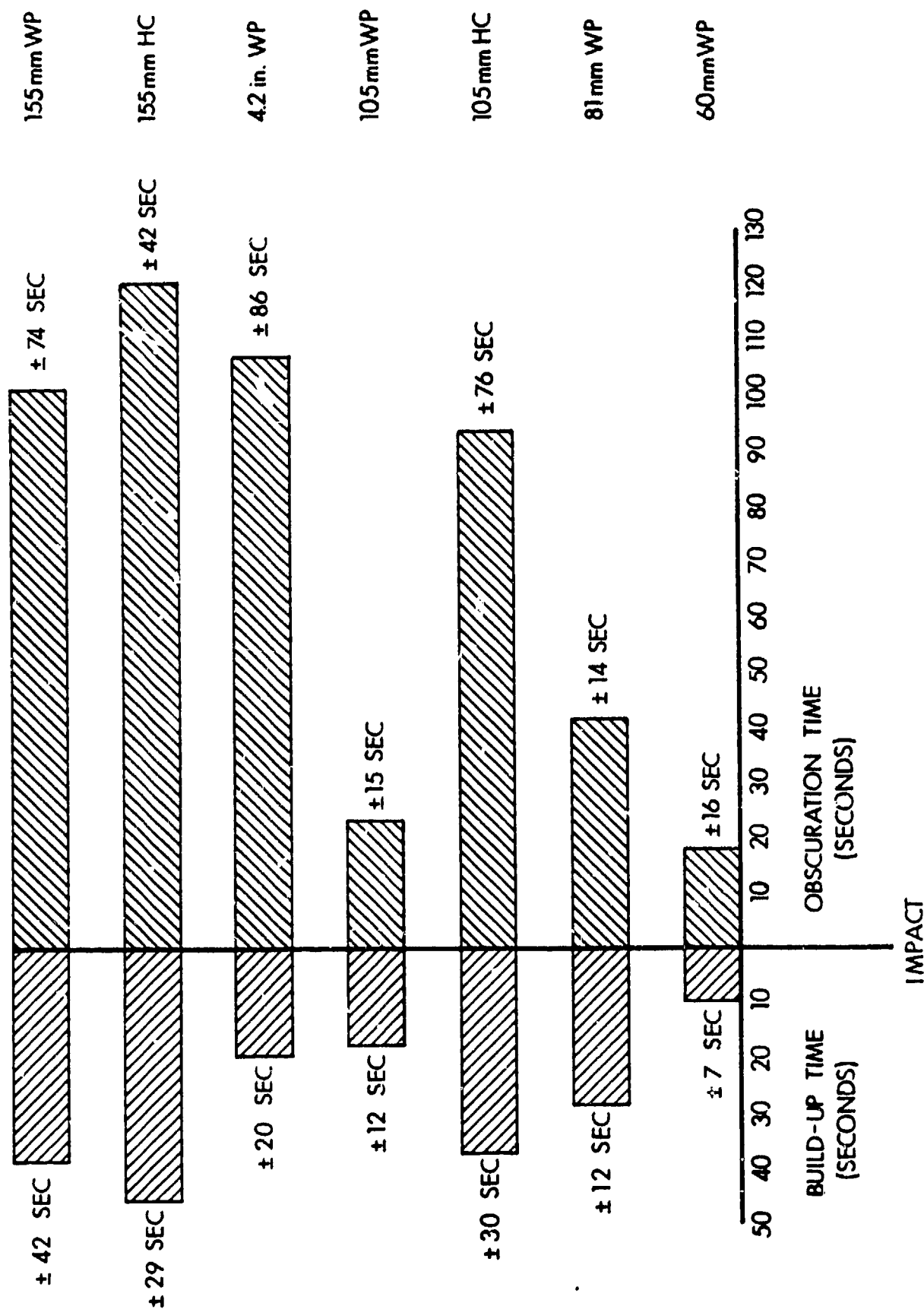


Figure 3.23 Average Build-up Time and Obscuration Time for the Seven Types of Smoke Rounds as Determined by the Combination of Position and Rounds Data.



## APPENDIX A

### REDUCED OBSERVER DATA

The data on the following pages are the reduced observation data which were used in the analysis contained in the report. These data were used in developing the time history of the average missions and performing the Analysis of Variance for the effects of number of rounds, types of rounds, and position of observers on the duration of smoke obscuration.

# REDUCED OBSERVER DATA

Mission	Type Round	Number of Rounds	Time to Obscure/Time Obscured (Seconds)			
			OP1	OP3	Bunker	OP6
4	155mm WP	2	5/40	5/80	60/60	180/240
5	"	2	9/80	5/15	30/90	315/0
6	"	6	4/58	55/-	60/90	60/360
7	"	6	3/125	5/110	30/210	45/165
8	"	4	3/140	30/55	60/90	60/60
9	"	4	10/110	33/355	60/90	105/30
10	"	6	6/105	20/80	60/120	150/165
13	"	2	2/100	10/30	0/60	90/15
15	"	6	5/65	10/40	60/30	90/105
18	"	4	5/70	-	0/60	75/90
21	"	6	60/40	-	60/60	75/285
25	155mm HC	2	20/140	-	25/50	30/135
26	"	2	30/105	35/70	30/75	15/90
31	"	2	-	90/60	10/147	60/75
31A	"	2	50/125	65/40	40/120	30/120
32	"	2	50/130	225/125	15/220	15/150
33	"	2	85/145	70/120	20/175	-
37	"	2	15/165	35/75	5/55	-
38	"	2	95/105	90/90	20/130	45/120
38A	"	4	100/120	80/130	60/175	30/225
39	"	6	60/155	55/125	20/150	30/90
40	"	6	100/120	90/105	15/135	-
52	4.2Inch WP	4	365/25	2/93	45/105	30/240
53	"	4	5/300	20/90	35/130	15/105
54	"	6	15/235	20/460	10/130	60/210
56	"	2	10/170	20/85	15/150	30/120
57	"	2	0/100	0/45	25/20	45/165
58	"	4	0/190	2/83	15/30	15/120
63	"	4	0/35	0/50	30/60	-

REDUCED OBSERVER DATA (Cont'd)

Mission	Type Round	Number of Rounds	Time to Obscure/Time Obscured (Seconds)			
			OP1	OP3	Bunker	OP6
64	4.2Inch WP	4 (1 dud)	15/15	8/45	0/45	30/75
67	"	2	-	-	0/45	105/45
68	"	2 (1 dud)	-	-	5/40	30/75
69	"	4	7/50	5/65	10/35	45/60
70	"	4	5/85	4/86	15/-	75/105
79	105mm WP	6	15/30	-	1/2	45/30
80	"	6	-	-/15	30/15	-
81	"	4	15/45	30/30	25/15	-
84	"	2	15/15	15/10	5/10	-
85	"	2	15/30	30/45	5/10	15/15
86	"	4	14/26	15/10	10/15	15/45
87	"	4	3/23	20/5	5/15	-
88	"	6	-	10/10	10/25	-
89	"	6	2/43	50/10	10/15	-
90	"	4	30/55	30/20	5/10	-
SQ6	"	6	15/60	20/15	10/15	-
95	105mm HC	2	10/65	0/240	75/105	75/90
96	"	4	15/200	0/120	30/90	15/75
97	"	4	20/75	60/60	75/30	30/120
99	"	6	-	0/60	105/15	60/45
100	"	2	-	60/60	45/120	75/30
101	"	6	5/105	60/60	25/50	15/60
110	"	6	15/375	60/60	45/60	45/60
122	81mm WP	1	15/25	-	15/30	-
123	"	3	30/55	42/25	15/45	-
124	"	3	-	-	30/60	-
125	"	6	-	-	35/50	-
126	"	6	-	-	45/40	-
137	60mm WP	1	-	5/0	0/0	-

REDUCED OBSERVER DATA (Cont'd)

Mission	Type Round	Number of Rounds	Time to Obscure/Time Obscured (Seconds)			
			OP1	OP3	Bunker	OP6
138	60mm WP	3	0/35	-	5/5	15/15
139	"	3(1 dud)	15/15	-	15/20	-
140	"	6(1 dud)	10/40	20/5	15/20	15/15
141	"	6	0/60	-	10/25	15/45
142	"	3	-	-	10/15	-
145	"	3	5/10	-	5/40	-
146	"	3(1 dud)	-	-	15/10	-
147	"	6	0/0	-	-/10	-
148	"	6(1 dud)	22/15	-	5/30	-
149	"	3	18/5	-	0/0	15/15

APPENDIX B  
METEOROLOGICAL DATA AND CLOUD DIMENSIONS

The meteorological data and cloud dimensions for most of the missions of battery/platoon size and greater which were used in the analysis are contained in Table B-1. The definition of terms used in the table are listed below.

1. Temperature: The 3 readings are for temperatures (averaged over the 3 meteorological towers) at heights of 1/2, 4, and 16 meters.
2. Wind Speed & Direction: The values shown are the averages at the 3 heights from the 3 meteorological towers.
3. Length: The effective distance with the wind. (Effective implying visual obscuration).
4. Width: The effective distance perpendicular to the wind.
5. Height: a. For HC munitions this is the average effective height.  
b. For WP munitions this is the effective height.
6. Peak Height: a. For HC munitions this is the maximum effective height of the cloud.  
b. For WP munitions this is the height of the pillars.
7. Time to Develop: The first number is time to intermediate cloud size, while the second number is time to develop to the size shown.
8. P = In this view, the smoke pillared i.e., no one large cloud.
9. ND: No Data.
10. PTD: Rapidly Pillars to Dissipation.

TABLE B-1. METEOROLOGICAL CONDITIONS AND CLOUD DIMENSIONS OF THE MISSIONS  
USED IN THE ANALYSIS WHICH WERE OF BATTERY/PLATOON SIZE OR GREATER

Caliber	Type	Number of Rounds	Time	Mission Number	Temperature (°F)	Wind Speed (MPH)	Wind Direction (Degrees)	Relative Humidity (%)	Length (Meters)	Width (Meters)	Height (Meters)	Peak Height (Meters)	Time to Develop (Sec)
155mm	WP	6	1007	6	39/37.5/36.9	5.5	185	48	130 ± 15	59 ± 5	26 ± 2	120 ± 7.5	15/
155mm	WP	6	1019	7	41.3/40.2/39.3	6.6	207	48	397 ± 45	72 ± 9	31 ± 2	118 ± 7.3	15/
155mm	WP	6	1052	10	45/43.1/42.3	11.0	194	47	470 ± 48	116 ± 12	30 ± 2.5	104 ± 6.5	15/
155mm	WP	6	1356	15	51.8/51.7/50.8	9.0	173	42	656 ± 70	56 ± 7	18 ± 2	98 ± 6	15/
155mm	WP	6	1503	21	54.5/54/53.3	9.2	177	38	86 ± 3	P	42 ± 3	115 ± 7	15/
155mm	HC	6	1528	39	40/39.6/39.3	7.5	354	50	329 ± 9	155 ± 3	22 ± 2	43 ± 3	60/90
155mm	HC	6	1534	40	39.6/39.5/39.2	7.3	359	50	329 ± 32	88 ± 5	35 ± 3	55 ± 3.5	60/90
4.2"	WP	4	0829	52	50/50.1/50.2	11.6	204	71	291 ± 22	ND	30 ± 3.5	ND	15/30
4.2"	WP	4	0840	53	50.7/50.7/50.5	10	204	70	303 ± 22	32 ± 6.5	17 ± 1	80 ± 4	ND
4.2"	WP	6	0850	54	51.4/51.2/50.8	11	199	69	354 ± 11	95 ± 5.5	31 ± 3.5	92 ± 5.5	ND
4.2"	WP	4	1034	58	59.6/57.9/57.2	16.8	204	54	287 ± 30	57 ± 6	25 ± 3	60 ± 5.5	20
4.2"	WP	4	1500	69	72.6/72/71.0	15.6	176	32	333 ± 38	76 ± 4	21 ± 3.5	71 ± 4	ND
4.2"	WP	4	1504	70	72.1/71.2/70.9	16	172	32	198 ± 5	ND	14 ± 2	ND	15/20
105mm	WP	6	1245	79	58/56.2/54.8	14.1	352	45	17 ± 3	100 ± 12	57 ± 4	ND	15/30
105mm	WP	6	1250	80	58.3/56.8/55.5	14.3	352	45	34 ± 5	80 ± 7	46 ± 4	66 ± 5	15/25
105mm	HC	6	1330	99	65.1/63.2/62.1	10.4	272	33	234 ± 16	200 ± 22	28 ± 3	71 ± 5	45/90
105mm	HC	6	1520	101	68.3/67.3/66.6	9.8	323	37	225 ± 5	200 ± 20	19 ± 2.5	55 ± 3.5	45/90
105mm	HC	6	1535	110	68/67.6/67.1	8.2	320	37	462 ± 10	213 ± 7	24 ± 3	ND	30/75
81mm	WP	3	1210	124	42.7/42.3/42	5.5	346	81	P	8 ± 1	28 ± 3	PTD	30
81mm	WP	6	1216	125	42.7/42.3/42	3.3	349	81	126 ± 14	48 ± 6	34 ± 3	PTD	30/90
81mm	WP	6	1226	126	43.4/42.7/42.2	2.8	340	81	49 ± 6	32 ± 3	87 ± 6	PTD	20/60
60mm	WP	3	1308	138	69.1/67.8/66.6	8.8	228	38	173 ± 10	23 ± 2	22 ± 2	PTD	15
60mm	WP	5	1315	140	70.1/68/67	9.0	254	36	116 ± 9	71 ± 6	17 ± 6	42 ± 3.5	17
60mm	WP	6	1319	141	69.2/67.1/66.5	9.2	230	36	117 ± 12	47 ± 4	17 ± 3	69 ± 5	15
60mm	WP	3	1322	142	70.3/68.2/67.1	7.3	227	34	54 ± 6	P	14 ± 2	40 ± 3	15
60mm	WP	3	1450	145	70.7/69.5/68.6	6.0	256	36	40 ± 3	P	14 ± 2	36 ± 3	15
60mm	WP	3	1455	146	70.5/69.9/68.6	5.3	268	36	17 ± 2	10 ± 1.5	23 ± 3	PTD	10
60mm	WP	6	1502	147	70/69.8/68.9	3.2	277	36	32 ± 4.5	16 ± 2	28 ± 3	60 ± 4.5	15
60mm	WP	6	1505	148	70.8/70/69.6	4.3	334*	36	32 ± 4.5	17 ± 2	48 ± 3.8	PTD	15

## APPENDIX C

### FT. STILL SMOKE TEST AMMUNITION

1. Projectile, 155mm, Smoke HC, M116E1(B1), w/o fuze.
2. Projectile, 155mm, Smoke, WP, M110E2, w/o fuze.
3. Cartridge, 105mm, Smoke, HC, M84B1, w/Fuze, M565.
4. Cartridge, 105mm, Smoke, WP, M60A2, w/Fuze, M557.
5. Cartridge, 4.2 inch, Smoke, WP, M328A1, w/Fuze, M48A3.
6. Cartridge, 81mm, Smoke, WP, M375A2, w/Fuze, M524A6.
7. Cartridge, 60mm, Smoke, WP, M302A1, w/Fuze, M527B1.
8. Charge, propelling, 155mm  
    M4A2 White Bag  
    M3A1 Green Bag
9. Primer Percussion, M82
10. Fuze, MTSQ, M501 (for use w/M116 BE rounds)
11. Fuze, MTSQ, M564 (for use w/M110 WP rounds)

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